Working Paper Sustainability and Innovation
No. S 08/2015

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International Transfer of Technologies for Climate Adaptation - The Case of Membrane Bio-Reactors

Fraunhofer ISI

MERIT International transfer of climate technologies

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Abstract

Existing research on the international transfer of climate technologies has so far largely concentrated on the transfer of mitigation technologies. However, the UNFCCC's decision to adopt the Cancún Adaptation Framework reflects the increasing political priority that is given to climate adaptation in general, as well as to the development and transfer of adaptation technologies. Given this situation, the objective of this case study is to explore the specific drivers and barriers pertaining to the international transfer and diffusion of membrane bioreactors (MBR), a water treatment technology that enables the reclamation and reuse of water and helps to reduce the negative impacts of climate change. While this technology has largely been developed in industrialized countries, many of those countries that are most vulnerable to draughts and water scarcity belong to the developing world. Therefore, this case study analyzes the international transfer of MBR technology to two emerging economies, Brazil and China. Methodologically, the case study combines quantitative evidence, e.g. trade and patent data, with qualitative evidence gained from the analysis of the relevant legal and political framework in Brazil and China, as well as from insights gained from eight personal interviews with experts representing MBR companies and policy makers.

Keywords: International Technology Transfer; Climate Adaptation, Membrane Bio-Reactors

Acknowledgement: This work was supported by the German Federal Ministry of Education and Research under Grant 01LA113DA.

1 Introduction

Enhancing the international transfer of climate technologies between the technologically advanced industrialized countries and the developing world is a stated objective of the United Nations Framework Convention on Climate Change (UNFCCC) and is widely regarded as an important solution to the global problem of climate change. Existing research on the international transfer of climate technologies has so far largely concentrated on the transfer of mitigation technologies, see e. g. Ockwell/Mallett (2012). However, the UNFCCC's decision to adopt the Cancún Adaptation Framework reflects the increasing political priority that is given to climate adaptation in general, as well as to the development and transfer of adaptation technologies (Olhoff 2015). Given this situation, the objective of this case study is to explore the specific drivers and barriers pertaining to the international transfer and diffusion of membrane bio-reactors (MBR). In many regions, climate change is expected to negatively affect the sustainability of water supplies and to increase the risk of draughts. An MBR is a water treatment technology that enables the reclamation and reuse of water on high quality levels and can thus help to reduce the negative impacts of climate change on natural water supplies. While the MBR technology has largely been developed in industrialized countries, many of those countries that are most vulnerable to draughts and water scarcity belong to the developing world.

This working paper analyzes the international transfer of MBR technology to two emerging economies, Brazil and China. Methodologically, these two case studies combine quantitative evidence from, e.g. trade and patent statistics, with qualitative evidence gained from the analysis of the relevant legal and political frameworks in Brazil and China, as well as from insights gained from eight personal interviews with experts representing MBR companies and policy makers.

In order to arrive at conclusions regarding the relevance of MBR specific drivers and barriers to technology transfer, we start with a description of the MBR technology (chapter 2). Then, we analyze the basic conditions for the application of MBR technology in Brazil and China, in particular addressing the natural and physical conditions as well as the relevant institutional setting in these two countries (chapter 3). Chapter four addresses the two countries' absorptive capacity with regard to MBR technology. In chapter five the strategies of MBR companies regarding market entry and penetration of the Brazilian and Chinese market are discussed. The concluding chapter presents the most important drivers and barriers to the transfer of MBR that have become evident from the two cases.

2 Technology and value chain

2.1 Description of MBR technology and its potential role in adapting to climate change

An MBR is a wastewater treatment system that combines a conventional biological aerobic treatment with physical membrane filtration. In contrast to the predominant conventional activated sludge (CAS) treatment which uses gravity settling in a secondary clarifier to separate solids from the treated effluent, an MBR uses physical membrane filtration to withhold particles exceeding the pore size of the membranes. Special process steps including aeration or cross-flow have to be employed to avoid clogging of the filtration membrane due to the high concentration of suspended solids in the wastewater sludge. The filtration unit is usually equipped with either microfiltration membranes (MF) with a pore size of 0.6 µm or ultrafiltration membranes (UF) with a pore size of 0.1 µm,[1] which both prove sufficient for effectively withholding suspended solids and yield a high degree of disinfection by removing pathogens, bacteria and viruses. The main application of MBRs is their use as an effective process technology for tertiary treatment and reclamation of industrial or municipal wastewater (Hermanowicz 2011).

Compared with conventional wastewater treatment such as activated sludge (including secondary settlement), rotating biological contactor (RBC) or sequencing batch reactor (SBR), the main advantages of MBR are (Judd and Judd 2011):

- Compact size allowing its installation and operation under very restricted special conditions. This small spatial footprint is due to the lacking need for large settlement tanks, but more so to the fact that threefold higher concentrations of suspended solids can be achieved;
- Modular design making up or down sizing more economical. In this context, it is emphasized by Lesjean et al. (2011) that treatment capacities below 50 are as yet not cost-effective due to the inefficient down-scaling of larger plants, while above 5000 person equivalents, economies of scale can be realized more easily by conventional plants;

1 While the filtration stage using MF or UF may be the final treatment step in many applications, it can be expanded by a subsequent treatment stage using nano-filtration (NF) or reverse osmosis (RO) to remove remaining dissolved substances such as salts or organics.

- High quality of effluent water allowing for discharge into sensitive water bodies (e.g. bathing lakes) and, alternatively, enabling the use of the run-off for high-quality purposes like bathing/shower, washing, cleaning (in private households) and irrigation (of municipal parks or in agriculture);
- Ease of operation with high automation potential.

The disadvantages are actually considerable, but most of these challenges appear to vanish with time or upon more careful inspection:

- High installation cost especially for small plants, limited membrane life due to fouling and high energy demand still amount to substantially higher costs as compared to the conventional processes. But all of them are believed to further decrease in the future due to continued standardization of the installation design and its operation and the use of innovative (membrane) materials, as they have done in the past.[2]
- If the MBR run-off is used for health-sensitive human purposes more (costly) monitoring is needed to guarantee safety, but this argument would equally apply to instances of high-quality water reclamation using other technologies.
- Chemicals used for cleaning the membranes are offset by the reduction of the amount of chemicals used in wastewater treatment (especially settling).

The main environmental advantages of MBR are the small spatial footprint and the high quality of the water run-off, which not only enables the more efficient use of land and protects the quality of the receiving water bodies. Together, both factors including the high modularity also allow MBR to be integrated in existing urban settlements. Thereby they not only complement the existing conventional (waste)water infrastructure, but by implementing wastewater treatment on-site, i.e. near the residential water users and potential consumers, they also form the basis for more extended water reclamation and reuse. The latter point is also relevant with respect to the adaptation to climate change, because MBR can be a counter-measure against the impacts of the increasing frequency and duration of draughts, which represent typical instances of climate change. In this case, the reclamation and reuse of water relaxes the strain on natural water sources, especially when they are under pressure and it avoids the existing (scarce) sources being spoilt by poorly or untreated wastewater.

2 Hermanowicz (2011) reports a reduction of annual costs from USD 0.90/m^3 of treated wastewater in 1995 to USD 0.08/m^3 in 2005. The main part of this is owing to decreasing installation costs, but also operation and maintenance (O&M) are expected to decrease by 15 to 20 percent until 2017 (Peng 2012).

Another point of relevance in the context of climate change is that MBR plants form closed containments. As a consequence, unlike conventional wastewater treatment plants, untreated wastewater cannot escape MBR plants in case of floods, which are expected to increase in frequency and intensity with ongoing climate change.

2.2 Integration into existing infrastructure

MBR are autonomous devices requiring a power supply for the operation of pumps and the process control. They treat incoming wastewater and transform it into a sort of raw water that can be used for many purposes like cleaning, washing and toilet flushing. After additional treatment by such processes as reverse osmosis and ultra-violet light exposure, the water can even be used as drinking water (see NEWater in Singapore as an example), although this type of use can be subject to cultural and personal restrictions. In any case, MBR are for this reason ideal for supporting local water cycles.

Regardless of this high degree of autonomy, MBR can also easily be used to complement an existing, conventional, centralized water infrastructure, especially when the capacity of the latter is exceeded by an increasing number of users. In this case, the wastewater of a residential area, a block of houses or a multi-apartment building is fed to an MBR (thereby relieving the load of the central wastewater system) and the cleaned wastewater can be used either locally or disposed anywhere without danger for human health or the environment. The compact size of the devices is especially useful in this context, as it allows them to be integrated easily in any kind of building.

2.3 Components of the technology, their degree of technical advancement and implications for international technology transfer[3]

The information provided in this sub-section goes a bit deeper into the technical details of MBR technology. It does so in order to exhibit the somewhat ambiguous nature of MBR: on the one hand, the components and the basic function are well known and do not appear to be very complicated. On the other hand, in practice, the challenge often lies in the details, which distinguish a well working from a poorly working system.

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3 Main reference for this section is Judd and Judd (2011).

Membrane filtration is based on semi-permeable membranes allowing some chemicals to pass through them (forming the permeate) while rejecting others (forming the retentate). According to the size and other properties of the permeating molecules four key membrane separation processes are distinguished: reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF). In all cases, the membranes act like sieves and are defined according to the size of the smallest molecules they reject. The smaller the pore size, the more pressure has to be exerted to drive the filtration process. Especially in the case of RO and NF, additional separation mechanisms are used, including selective extraction and diffusion, which are based on chemical interaction between the membrane and the filtrate/retentate. In MBR, mainly MF and UF is used and, accordingly, only the sieving mechanism is relevant. In addition to pressure-driven processes, MBR sometimes uses electrodialysis, which can extract ions like nitrate or those associated with hardness and salinity.

Rejected molecules in the retentate tend to accumulate at the membrane surface and in its structure and lead to a gradual reduction of the flow of water through the membrane. Referred to as fouling, this phenomenon is associated with all types of membrane filtration; it leads to an increase in trans-membrane pressure and, eventually, to the need for replacement of the membrane. In the following, certain aspects of the MBR technology will be discussed, which are relevant for achieving the main purpose of MBR, the cleaning of wastewater, and thereby avoiding fouling as its main complication.

2.3.1 Membrane materials

While membranes play a central role in the functioning of MBR, the membrane materials are important in several respects. In most cases, membranes comprise of a thin surface layer providing the required selectivity on top of a thicker, more open porous support layer, which provides mechanical strength. The challenge with respect to the (selective) surface layer is to ensure simultaneously good selectivity and high throughput. This is achieved by using materials with high surface porosity and narrow pore size distribution. The support layer, by contrast, must combine high porosity (in order to add as little as possible to the flow resistance) with mechanical strength in order to ensure high cost effectiveness and a long lifetime. This also includes resistance to thermal and chemical attacks (e.g. extreme pH, high concentration of oxidants), which accrue from either the wastewater to be treated or the chemicals used for cleaning the membrane. With regard to the latter point, the membrane should ideally provide by its own chemical nature some resistance to fouling. Other parameters that need to be controlled are the hydrophilicity (which influences permeability and selectivity) of the membrane materials and their suitability for certain manufacturing processes (e.g. the manufacture of hollow fibres). This indicates that the development of new membranes is a demanding task. While it appears to be possible to produce low or medium performing membranes with moderate technical effort, these membranes are not competitive in most modern applications (including MBR), because they are limited with regard to lifetime and performance and do not allow for the exploitation of the full potential of these appliances. The technically more advanced membrane materials, on the other hand, which allow for the exhaustion of these potentials, are certainly high-tech.

2.3.2 Membrane configurations

The configuration of the membrane describes its geometry and the way it is mounted and oriented in relation to the water flow and other aspects relevant in MBR and is crucial in determining the process performance. Ideally, the membrane should be configured so as to have

- a high membrane area to module bulk volume ratio (i.e. packing density),
- a high degree of turbulence for mass transfer promotion on the feed side,
- a low cost (incl. energy cost) per unit of water effluent and
- a design that facilitates cleaning

Unfortunately, many of these characteristics are in conflict with one another. Promoting turbulence, for instance, results in increased energy use and higher operation cost and is adversely affected by a high packing density. Packing density also affects the ease of cleaning. Low packing density, however, increases the unit cost of the membrane and of the MBR device altogether. Due to these trade-offs, of the six principal configurations currently employed in membrane processes only three are suitable for use in MBR: Plate-and-frame or flat sheet (FS), hollow fibre (HF) and multi-tubular (MT). Which one is used, also depends on the general MBR configuration, which will be discussed below. And each of the membrane configurations has its pros and cons. Beyond the basic configuration, certain additional aspects such as the distance between plates or fibers or their integration into modules are crucial for the effectiveness and ease of subjecting them to backflow or cleaning or to avoid fouling and clogging in the first place. With regard to the necessary know-how, the development and manufacture of membrane configurations requires a lot of experience from running different membrane configurations. With respect to the necessary level of invention and the respective frequencies, these innovations are better classified as medium than high-tech.

2.3.3 MBR configurations

While the membrane configuration refers to the structure and function of the filter unit, the configuration of MBR is about the way the filter unit and other components are integrated within an MBR facility. Basically, two main MBR process configurations can be distinguished in the context of wastewater treatment: submerged or immersed (iMBR) and sidestream (sMBR).[4] iMBR is generally less energy-intense than sMBR, because in the former all energy is used to force the liquid through the membrane, while in the latter additional energy is needed to drive the side-stream. The advantages of the sMBR, on the other hand, are

- the possibility to decrease fouling through increasing the cross-flow velocity,
- the separation of the bio-reaction and membrane filtration compartments and the resulting possibility of easier cleaning and other maintenance operation,
- the possibility to optimize aeration for high oxygen transfer, rather than seeking a compromise between membrane aeration and oxygen dissolution in single-tank iMBR.

The arguments explicated above show that the physical and cost effectiveness of either MBR configuration represents a delicate balance between a number of different factors, the relevance of which depends very much on the respective circumstances: the properties of the waste water, the energy supply, the need for uninterrupted operation and so on. Like for membrane configuration, approaching optimum configuration requires a lot of operation experience; however, the level of invention and the respective frequencies are not very high and so, the innovations can be classified as medium-tech.

2.3.4 Implications for international technology transfer

It is evident from the different technology components – membrane materials, membrane configurations and MBR configuration – that some components have substantial high-tech potential. The majority of the components, however, while showing a high degree of complexity with regard to their interactions, are not

4 Beside biomass rejection, two other membrane process modes – extraction and diffusion – are not relevant in the context of wastewater treatment and therefore not discussed here.

high-tech, when it comes to the approaches chosen to deal with them and solve the upcoming challenges. At the same time, it is quite evident that the MBR technology comprises to a large extent process-related know-how, which is not codified in the form of patents, but manifests itself as experience on the part of those engineers and scientists, who actually develop or operate the appliances.

This leads to an important conclusion: In order to transfer MBR-related knowledge from the country of origin to any other country, it will hardly be possible to separate the know-how concerning the technical appliance (i.e. the MBR device) and its operation. The former simply does not work without the latter. So, on the one hand, it will be difficult for countries such as Brazil and China to access MBR-related knowledge by importing and re-engineering of MBR devices. On the other hand, it will neither be possible for MBR exporting countries to merely export the respective appliances. Rather it will be necessary to also import the operative know-how by either dispatching experts from the country of origin or, preferentially, by instructing and qualifying people within the importing country.

2.4 Technology development, value chain and global diffusion of MBR

2.4.1 Technology development

The first commercial membrane bioreactors were developed in the 1960s by the U.S. company Dorr-Oliver Inc. However, high membrane costs together with the problem of fouling and high energy demand limited the application of these MBRs to small industrial niche markets where good effluent quality was required irrespective of high costs (Judd and Judd 2011). While the first MBRs were less successful on the U.S. market in the 1970s, they diffused more successfully on the Japanese market based on license agreements between Dorr-Oliver and Sanki Engineering Co. Ltd. Around that time the Canadian company Thetford Systems, later known as ZENON Environmental also launched an MBR for domestic wastewater treatment. Similar developments also began in France and later on in the UK. A major breakthrough for commercial application was marked by the invention of submerged MBRs[5] in Japan as part of a government-funded research program at the end of the 1980s. The integration of

5 Until then the standard MBR design was external MBR with the filtration unit located outside the wastewater treatment tank.

the previously externally located membrane unit into the bioreactor combined with the use of membrane aeration to limit fouling reduced operating costs significantly and made the application of MBRs more economical in other sectors apart from industrial niche markets. Since then Japan pioneered the MBR development with companies such as Kubota, Asahi Kasai or Mitsubishi Rayon and become the leading market for small-scale domestic wastewater treatment systems, operating about 3800 MBR plants compared to about 600 in Europe and about 300 in China (Wang et al. 2008; Lesjean and Huisjes 2008; Itokawa 2009; Judd and Judd 2011). Due to the early adoption of MBR, Japanese suppliers could evidently benefit from higher penetration rates for a significant time period and subsequently gain market knowledge as well as user feedback to further improve the technology and retain a strong position against other countries, particularly in membrane production. Apart from Japan other early suppliers of MBRs emerged in Canada (ZENON Environmental, which is now part of GE Water Technologies) and in Germany (Wehrle AG) (Sutherland 2009).

2.4.2 MBR Value Chain

The MBR value chain is split into four production stages. On the first stage is the chemical industry which supplies the raw substances. These are used by membrane suppliers for the production of HF, FS and MT membranes. These membranes are then packaged together and sold as MBR modules by MBR equipment suppliers. Engineering, procurement and construction (EPC) companies and design institutes are then responsible for the integration of the MBR modules into the MBR treatment system and specify the local design requirements. Apart from a small number of system solution suppliers that are horizontally integrated along the complete value chain, generally there are a few membrane producers, a large number of small MBR module and equipment suppliers and a well-sorted number of foremost national EPC companies that are specialised on MBR system integration.

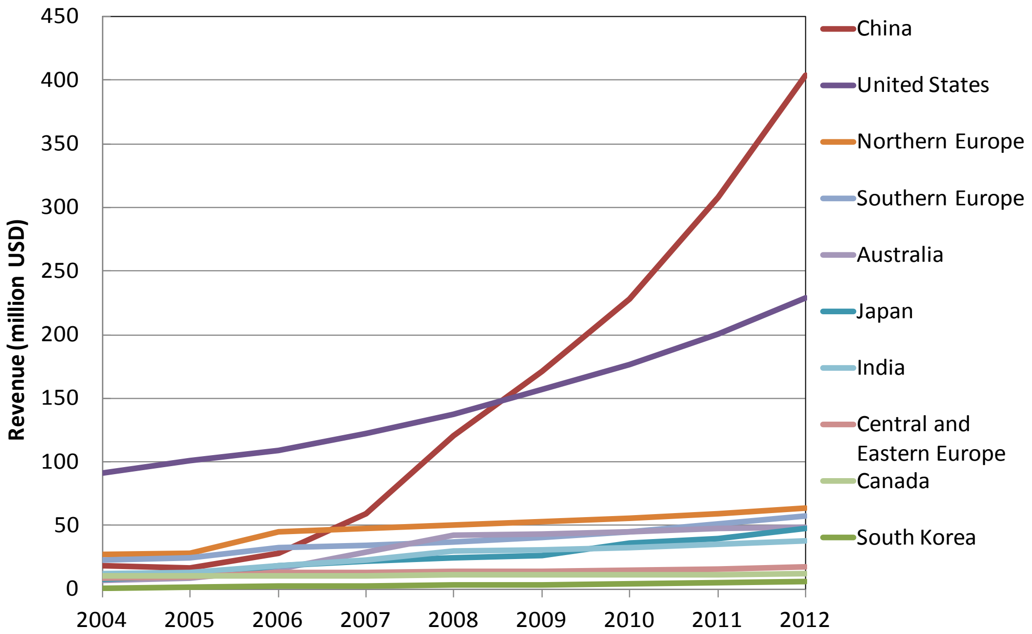
Figure 1: Companies along the MBR value chain. Shape sizes correspond to the number of companies

Source: Orzanna (2013)

2.4.3 Global Diffusion

With the maturing of the technology other developed markets such as Europe and North America soon followed with a wider adoption from the late 1990's onwards. Around the turn of the millennium MBR technology was increasingly acknowledged by industrial experts and academics as the best available technology for wastewater treatment with reclamation purposes. From 2000 to 2012 this has led to significant global growth in terms of the number of plants and to a thirteen-fold increase in installed capacity (MBR Site 2012a), yet with major differences between regions. In 2003, 73 percent of all plants were operated in Asia, followed by North America with 16 percent and Europe with 11 percent (Pearce 2008). Within the last decade this share remained stable (Frost & Sullivan 2008; see also Figure 2) with strong demand arising from Asian-Pacific and increasingly from Middle East countries. This strong diffusion of MBR technology worldwide reveals its maturity and its chances in becoming a global standard design.

Figure 2: Global diffusion of MBR technology approximated by sales trends



Source: Own calculations based on Frost & Sullivan (2008) and Frost & Sullivan (2011b)

In 2011, the global MBR market was estimated at USD 838 million and is projected to grow at an average annual rate of 22.4 percent, reaching a total market size of USD 3.44 billion in 2018 (WaterWorld 2012). In comparison, the Chinese market was valued USD 308.1 million in 2011 – thus constituting about one third of the global market - and is expected to grow at an even higher rate of 28.9 percent, reaching a total market size of USD 1.35 billion in 2017 (Frost & Sullivan 2011a). Key drivers facilitating the high growth rates in China are increased confidence in the technology and public awareness, an increasing number of domestic manufacturers, a set of new policies addressing water quality and the need for wastewater reclamation, and reductions in membrane costs due to advancements in the technology and domestic production that lead to cost advantages against other water supply sources such as desalination or the South-to-North Water Diversion Project (Frost & Sullivan 2011a; ADB 2012).

3 Basic conditions for the application of MBR technology in Brazil and China

While there are fundamental arguments why humans need a safe water supply and sanitation, the reasons for employing MBR technology are more specific. As was shown in section 1, compactness, scalability and high effluent water quality can be considered as strengths of the MBR technology, while high technical effort and cost are some of its weaknesses. In order to see if the circumstances for the employment of MBR in Brazil and China are favorable and bring to bear its advantages rather than its cost, this section takes a look at the natural or physical conditions of MBR use as well as the relevant institutional setting in both countries.

3.1 Brazil

3.1.1 Natural and physical conditions of MBR use

In 2013, Brazil had a population of 200 million and a total water resources availability of 8647 km^3, which corresponds to 43,235 m^3 per capita (FAO Aquastat, 2014), about five times higher than the global average. This means that Brazil is characterized by an extraordinary abundance of water, comprising 13.8% of the world’s fresh water resources.

The Brazilian area of 8.5 million km^2 is continental size and shows a water resource potential of extremely uneven regional distribution, with annual rainfall varying between 600 to 3600 mm. Although natural water conditions are generally favorable, the semi-arid northeastern region has a high susceptibility to droughts, and the rapid urbanization and industrialization have led to serious problems of water pollution and human induced water scarcity, particularly in the southeastern part of the country, where most of the industrial and urban agglomerations are situated. São Paulo for instance has today an effluent discharge of about the same volume as the natural flux of river waters that cross the city. In 2014 São Paulo water has been rationed due to less than usual rainfall, and the solutions appointed were building more reservoirs and reducing water loss in the pipes. And the São Paulo region is not the only one; in 2014 142 other cities had to ration water. The solutions generally appointed are extension of the supply of water, but not a better management of the used water (Strauch 2014).

A study conducted for the government of the São Paulo state by the Technology Center for Hydraulics and Water Resources, headed by Paulo Takashi Nakayama, says that the 2013/2014 draught in the Southeast of Brazil has a recurrence time of 3.378 years, and will not happen soon again[6], thus giving responsibility to nature only and claiming this would not happen in our lifetime again. Another study, by the UNICAMP University, using rainfall records since 1910, says the region may have entered a 30 year period of scarce rainfall, a normal cyclic phenomenon (Zuffo, 2015). Several news articles relate this draught to global climate change and compare this draught to others in the world like in the USA, Australia and Chile[7]. Another part of the explanation is given by the "flying rivers" research program[8], in which several institutions and universities participate, analyzing the effects of deforestation of the Cerrado and Amazon biomes on the hydrologic cycle that makes the rain come from the western Amazon region over several rain and evaporation cycles and over thousands of kilometers to the center-east and southeast of Brazil (Nobre, 2014). This study depicts a scary scenario for the case deforestation in the Cerrado and Amazon regions is not immediately stopped. A more immediate and technical explanation is the mismanagement of the Cantareira water system, the argument most used in the news and discussed in government meetings.

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6 This study is repeatedly cited on the internet and governor speeches, however not publicly accessible. See for example: http://sao-paulo.estadao.com.br/noticias/geral,seca-atual-so-ocorre-a-cada-3378-anos,1165826.

7 See for example in the news portal Terra: http://noticias.terra.com.br/ciencia/clima/seca-em-sao-paulo-comprova-crise-ambiental-mundial,6293a74d7ac8a410VgnVCM4000009bcceb0aRCRD.html.

8 Projeto Rios Voadores (www.riosvoadores.com.br).

The public efforts to manage the crisis range from building pipelines to more remote reservoirs, rationalizing water, asking the population to consume less, and water efficiency measures; however, water reuse is not part of government programmes (SABESP, 2014). According to a study of the UNICAMP University 95% of companies (industries, hospitals, hotels, among others) in São Paulo have no contingency plan to deal with water shortages, and only 12,5% have water reuse of any kind (Domingues & Bacic, 2014). In this context the 1st International Technical Forum on Direct and Indirect Effluent Reuse for Potabilization, realized in São Paulo, demanded changes in legislation and incentives for water reuse[9].

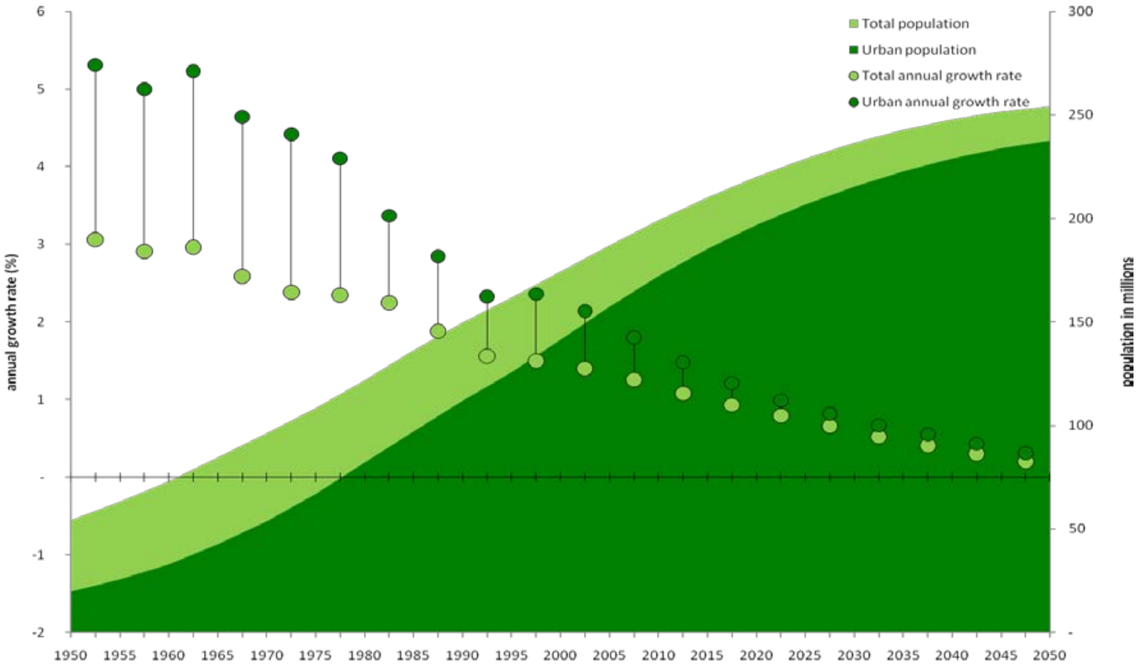
The analysis of the studies on the drought in the Southeast suggest that chronic water shortages will not be a problem only of the arid northeast or central Brazil anymore, but reached the megacities and large industrialized regions. Droughts and floods will become more often, and adaptation will become an increasingly pressing issue. Whilst impacts on agriculture and power generation and investment needs for adaptation are well studied, costs for urban infrastructure adaptation are unknown (Margulis & Unterstell, 2014).

Population

In the future, the water-related situation will be influenced substantially by two demographic factors: the increase in total population and, additionally, the increase in the share of urban population. As is shown in Figure 3, population growth in the time period from 2015 to 2050 will be much lower than in the past. Nevertheless, with growth rates around or below 1 percent, the total population is still expected to grow to above 250 million in 2050.

9 See Maxpressnet in: http://www.maxpressnet.com.br/Conteudo/1,711378,Crise_hidrica_em_Sao_Paulo_vira_tema_em_Forum_sobre_reuso_de_agua,711378,2.htm.

Figure 3: Demographic development of Brazil, 1950-2050



Source: UN Population Division

More crucially, urban population is, and will be, increasing with a higher rate than total population. Starting in the mid-20th century and led by the cities of the south-east and south, Brazil's industrialization process was accompanied by a profound transformation from essentially rural to predominantly urban settlement patterns. The rural to urban migration has been dramatic and created large informal settlements. Between 1970 and 1990 the average annual growth rate of urban population was at 3.7%. In the last decades, this rapid growth has slowed down to an average of 2.3% between 1990 and 2006, which is still above the world's average urban growth rate (UN 2010). In the future, the share of the urban population is expected to increase from 85 percent in 2015 to above 92 percent in 2050, i.e. from 175 to 238 million in absolute figures.

Water infrastructure

The water and wastewater infrastructure serving these people is characterized by a strong increase of coverage in the past decades. While in 1990, only 88 and 69 percent of the population came to enjoy improved drinking water supply and sanitation[10], respectively, these shares increased to 97 and 80 percent in 2008. In urban areas, the 2008 shares were even as high as 99 and 87 percent, respectively, while 87 and 37 percent of the respective population respectively benefitted from improved drinking water supply and sanitation in the rural area (UN 2010). However, even for the urban population, these figures and the situation they represent differ widely across Brazilian regions. While in the highly developed southeast 96 percent enjoy a save water supply and 70 percent wastewater collection, the respective figures drop to 92 and 26, respectively, in the northeast and 63 and 6 percent in the north (SNIS 2006 (www.snis.gov.br).

3.1.2 Institutional conditions of water management and MBR application

Water operation and management

The main features of the current sector structure in Brazil were established during the 1970s, through the implementation of the National Basic Sanitation Plan (PLANASA) by the military regime. Part of this plan was an administrative centralization process that effectively assigned water operation and management to the state level. After an initial success with a rapid expansion of service coverage, the PLANASA scheme eventually failed by the end of the 1980s.

The 1988 Federal Constitution shifted the ownership of Brazil's surface and groundwater from the private to the public domain. By delineating "federal waters" from "state waters" it made both the federal and the state governments responsible for managing water in their respective jurisdiction. Though the notion of private water ownership was abolished, authorized private use rights were allowed.

Water use concessions are granted by the water agencies according to criteria set by the river basin management committees, a development that after the Water Law of 1997 had been implemented 20 years ago is still not fully completed in most parts of the country. Thus water is used mostly without a concession and without payment.

10 Sanitation in this case is understood as wastewater collection, the share of the collected wastewater that is treated is lower. Therefore statistics for rural area are lower, because they are often not collected to a public sewer system.

Table 1: Laws, regulations and policies for the urban water sector in Brazil

Year	Title	Level	Significance for the urban water sector
1988	Federal Constitution	Constitutional	Shifted ownership of surface and groundwater from the private to the public domain; responsibility of federal and state governments for water management
1991	São Paulo Water Law	State Law	Creation of decision-making bodies at the state level and river-basin-level with stakeholder participation
1995	Public Concession Act	National Law	Opening of urban water services sector to private sector participation
1997	National Water Law	National Law	General framework for state water laws; establishment of National Water Resources Policy and National Water Resources Management System
2000	National Water Agency Law	National Law	Foundation of the Brazilian National Water Agency (ANA) as coordinator of national water resource management
2005	National Wastewater Resolution	National Environmental Council	Determination of parameters for wastewater run-offs into surface water bodies
2007	National Sanitation Law	National Law	Fundamental principles of modern water and sanitation management; municipal conceding authority over water and sanitation services; adoption of national guidelines

Sources: Strauch (2014)

Water supply and sewage collection are municipal responsibilities. In order to meet its responsibility the municipality can set up its own company or hire a company, which can be state-owned or private. With the water and sewage services under municipal management, to increase water or wastewater taxes is an unpopular measure to be taken, and thus investment capacity by municipal companies is limited as water sector financing has to be made mainly through taxes according to Art. 29 Sanitation Law 11.445/2007).

Since the 1990s, as a part of the economic liberalization policy of the Cardoso administration and as a means of overcoming fiscal restrictions and compensating increasingly lacking public investments, Brazil opened its urban water and sanitation sector to private participation. This policy was supported by international financial organizations as the World Bank and justified by the need to foster operation efficiency. The Public Concession Act of 1995 challenged the state monopoly particularly in metropolitan areas. Henceforth, Brazilian states took many different approaches for financing water and sanitation operations, including concessions to private investors. The private concessions in the 1990s resulted in bad experiences, which created a mindset against "privatisation of water", generating campaigns supported by the large state-owned sanitation companies. Resource mobilization through private investments has not nearly achieved the goal of the Cardoso government since the expiration of the PLANASA agreements had left a great deal of legal ambiguity regarding state vs. municipal responsibility for water services.

In addition to the legal uncertainties on the side of private investors, there has also been a strong political opposition against concessions to private companies and a strong skepticism concerning their role for social inclusion, as they are "widely viewed as inherently abusive in setting rates and unable or unwilling to serve poorer areas adequately" (Motta and Moreira, 2006). A well-defined regulatory framework that establishes and enforces high performance targets of service coverage and adequate quality standards therefore becomes an important institutional precondition for further privatization. Big steps towards a better regulatory framework were the law of Public Private Partnerships (PPP, Law 11.079/2004), law of public consortiums (11.107/2005), the new civil codex (10.406/2002) and the law of sanitation (11.445/2007), creating a different policy environment compared to the time of bad privatization experiences in the 1990ies. So, created in 2000 as an executive branch of the Ministry of Environment (MoE), the Brazilian National Water Agency (ANA) was given the mandate to enforce the National Policy on Water Resources. ANA has administrative and financial autonomy to regulate the multiple water uses, which shall ensure the highest possible efficiency in public and private water provision. According to Sabbioni (2008), the role of ANA as a regulator is yet to be defined.

The new National Sanitation Law, enacted in 2007, installs fundamentally new principles for water and sanitation management by accounting for the three-level structure (national – federal – local) of the Brazilian government (see Figure 4). It also introduces a national sanitation information system, which is fed by municipalities and their service providers (i.e. utilities). Sanitation funding is restricted to those municipalities/utilities which supply all requested information.

Figure 4: Structure of the National Sanitation System according to the Law of 2007

Source: Strauch (2014)

The typical 'problem-solving' organization in the Brazilian urban water and sanitation innovation system continues to be a large quasi-public company that jointly provides water and sanitation services to various municipalities within the state. For instance, the two Brazilian megacities São Paulo and Rio de Janeiro are served by SABESP and CEDAE respectively, which are mixed public-private companies with the majority share held by the state government. Both companies can be considered outcomes of the PLANASA scheme as CEDAE was created in 1975 when the State of Rio de Janeiro fused with the State of Guanabara and SABESP was created in 1973 as a result of a fusion of companies and autarchies that until then had managed the water service and sewage collection in the cities of the state.

Participation of civil society

Besides the academic research community, other knowledge sources such as water users and NGOs have been successfully integrated into the sector development through the creation of institutions for stakeholder participation. Beginning in 1991 with the São Paulo Water Law, Brazilian states began to create water laws that required, among other changes, the creation of decision-making bodies at the state level and at the river basin level that would bring together government, private sector and civil society organizations to produce general guidelines and plans for water policy, to deliberate on rules for bulk water changes and to monitor policy implementation. This innovative legislation marked a paradigmatic shift from technocratic supply-side oriented to a more participatory integrated management approach.

The National Water Law of 1997 – loosely inspired by the São Paulo model – created the general framework for the formation of later state laws. The law established the National Water Resources Policy and created the National Water Resource Management System, as a combination of public organizations, private entities, and civil society, with the expressed purpose of improving managerial coordination and resolving water conflicts within the federal framework. In order to counteract the tendency to centralized decision making, broad stakeholder involvement is ensured through the creation of participatory councils, which give local actors an arena to express their needs, build networks and acquire resources for influencing water policy.

Since 2003 the Ministry of Cities (MC) is entrusted with the responsibility to guide and monitor the urban water supply and sanitation sector. Thereby the notion of “water supply and sanitation” was progressively replaced by the concept of “basic sanitation”, which also integrates the collection, treatment and disposal of solid wastes, storm-water drainage, and the control of vectors of transmittable diseases. The 2007 National Sanitation Law has implemented more fundamental principles of modern water and sanitation management, as the strive for universalization of access to water and sanitation, integrative water resource management and economic stability, transparency and social control, security, quality and regularity. For the first time the law enables the adoption of national guidelines for public policy and management in the basic sanitation sector and establishes criteria for municipalities and states to access federal financing and determines the constitution of councils with the participation of civil society.

Table 2: Agencies involved in the Brazilian urban water sector

Agency	Responsibilities for the urban water sector
Ministry of Cities (MoC)	Monitoring the water supply and sanitation sector performance and establishment of directives for “basic sanitation”
Ministry of Environment (MoE)	National water policy
Secretariat of Hydraulic Resources (SRH)	Planning and regulation of all water uses
National Water Agency (ANA)	Planning and management of the national water resources, implementation of the national water policy and establishing criteria for granting of water usage rights and pricing mechanisms
National Council on Water Resources (NCWR)	Promoting the integration of water resources planning at the national, regional, and state levels and between user sectors
River Basin Committees (RBCs)	Forum for stakeholder participation (federal, state, municipal, water users, Water Resources Civil Organizations) in discussion and decision-making for water resource protection

3.1.3 More specific policies affecting the diffusion of MBR

Some municipalities in Brazil, such as Niterói, have water reuse laws and incentives in place. However, due to resolution 54/2005 of the national water resources council, no reuse for potability is allowed and technical norms are needed to guide the licensing processes of such systems. Government programs in water scarce areas, such as the Programa Agua para Todos at the federal level or the programs of the Tocantins state government, provide access to water to poor countryside populations, the first through desalination and the second through water storage.

3.2 China

3.2.1 Natural and physical conditions of MBR use

With an area of 9.6 million km^2 China is only slightly (by 13 percent) larger than Brazil. Being the most populous country in the world, however, China's 1.41 billion inhabitants (in 2013) represent a population seven times as large as that of Brazil (FAO Aquastat 2014).

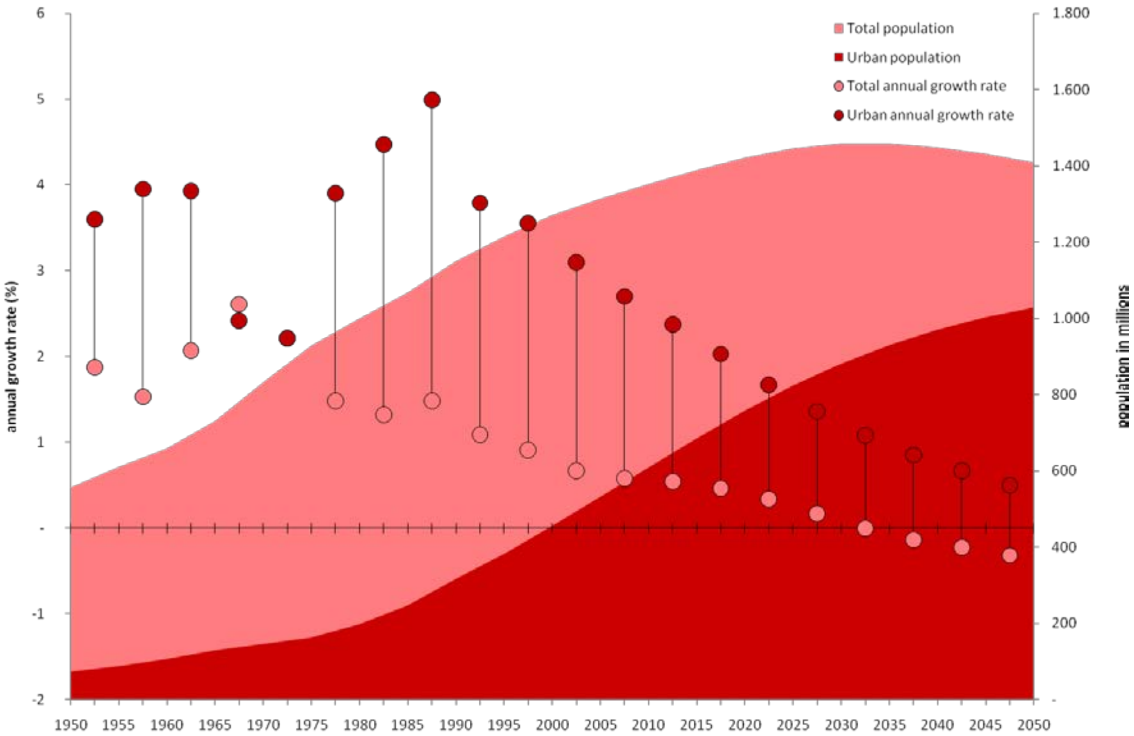
The mean annual precipitation in China is 648 mm (Saleth and Dinar, 2000), but water availability is unevenly distributed in terms of time and space. Affected by monsoon, precipitation occurs mostly in the summer months providing 60 to 80 percent of the total annual precipitation. This pattern tends to yield droughts in spring, and floods and waterlogging in the summer. In 2013, the total water resources availability was 2840 km^3 (FAO Aquastat, 2014). Hence, the water availability per capita is estimated to be 2004 m^3, which is only about one fourth of the global average and less than 5 percent of the respective figure for Brazil.

Beside the increasing population, a rapidly developing economic and social system, accelerated urbanization and improvements in the standard of living imply that China’s per capita water resources will decrease even further while demand will increase. China therefore faces huge challenges from water shortages and quality issues. Scarce water resources, particularly in northern China, led to over-extraction of surface and groundwater. About two thirds of all larger Chinese cities suffer from water shortages. At the same time, wastewater discharges from Chinese cities are a major cause of river pollution (OECD 2007). One of the most serious consequences is the deterioration of the quality of many drinking water sources. As urbanization and industrial development grow and water treatment facilities continue to be in dearth, surface and groundwater pollution is becoming increasingly severe. As a consequence, two thirds of the Chinese population is supplied with health threatening drinking water (Orlowski 2006) and major parts of the rivers are too polluted to allow for fishery (Sternfeld 2003).

Population

After the foundation of the People's Republic of China in 1949, the population grew with an average rate of between 1.5 and 2 percent until the late 1980s, when the propagation of the one-child family became effective. Since then, the growth rate decreased gradually to its actual level of about 0.5 percent and this decrease is expected to continue in the future, such that the population maximum is foreseen to be reached between 2030 and 2040. As is depicted in Figure 5, the population increase until then will only be a few percent and in the order of 100 million in absolute figures.

Figure 5: Demographic development of China, 1950-2050



Source: UN Population division

With respect to urbanization, in its beginning in the 1950s China was characterized by a large share of rural population (> 80 %), mostly working in agriculture. Until the mid 1960s, the share of the urban population hardly exceeded 18 percent and even decreased again slightly until the mid 1970s due to the anti-urbanization policy of the Mao regime during the Cultural Revolution. It was with Deng’s reform policy beginning in 1978 and the stepwise transformation towards market economy in the 1980s that urbanization growth accelerated again to rates between 4% and 5%. In the time to come, the displacement of large numbers of agricultural workers by the implementation of the agricultural responsibility system in conjunction with the restructuring of state-owned companies and the inflow of foreign direct investment created massive employment opportunities within urban areas, which led to unprecedented migration from rural to urban areas. This wave persisted until the 1990s when urban population growth returned to lower but still very high rates above 3 percent. By today, the urban population growth rate has reached 2.5 percent and it is expected to continue decreasing, but the urban growth rate will remain well above the total growth rate and so, the future urban population share is foreseen to increase far above today's 54 percent, reaching a prospected number of more than 1 billion urban population corresponding to a share of 72.9% in 2050 (UN Population

Division, 2008). The latter fact is also reflected in the number and size of Chinese cities: in 2007, with Shanghai ranking 6th (15.0 million inhabitants) and Beijing ranking 16th (11.1 million inhabitants), two of the world's nineteen megacities with more than 10 million inhabitants and a total of 14 cities with more than 3 million inhabitants were located in China.

Water infrastructure

The water and wastewater infrastructure serving this large number of people is characterized by a strong increase of coverage in the past decades. While in 1990, only 67 and 41 percent of the population came to enjoy improved drinking water supply and sanitation, respectively, these shares increased to 89 and 55 percent in 2008. While these figures are in general significantly lower than in Brazil, the increase is about the same. The effort behind these improvements becomes even more impressive, if absolute figures are considered, which are by a factor of 7 higher than in Brazil. In urban areas, the 2008 shares were even as high as 98 and 58 percent, respectively, while 82 and 52 percent of the respective population respectively benefitted from improved drinking water supply and sanitation in the rural area (UN 2010). While all other Chinese percentage figures are slightly below the Brazilian ones in 2008, the share of rural population with improved sanitation (52%) is higher than the respective share in Brazil (37%, see section 3.1.1).

3.2.2 Institutional conditions of water management and MBR application

Water operation and management

China has a centralized political system with considerable decentralized power across the four layers of government at the national, provincial, prefectural, and county levels. Legislation and regulation as well as planning and development responsibilities are with the national government. The provincial government historically played an advisory and oversight role, while local governments play the dominant role in infrastructure service provision and financing of the public utilities. The Chinese fiscal system is rather decentralized, with most of the tax revenues collected and spent at the local level.

Urban water supply and sanitation is the responsibility of cities under complex arrangements that differ substantially from one city to another. Local governments are responsible for urban water services, including tariff setting, subsidies, utility management, and definition of scale and scope. Many cities have established Water Affairs Bureaus that report to the MWR and are mandated to provide integrated water management and supervise urban water utilities, yet the MHURD still issues most of the policy guidance related to urban water utilities.

Table 3: National-level agencies involved in the Chinese urban water sector

Agency	Responsibilities for the Urban Water Sector
Ministry of Water Resources (MWR)	Water resource management, with a focus on quantitative aspects of surface water management, including constructing and protecting hydro-engineering projects, licensing and charging water resource fees, responsible for integrated water resource management, including water use and (in conjunction with MEP) water quality management
Ministry of Environmental Protection (MEP)	Management of the quality of water resources, development and monitoring of water quality improvement plans, environmental impact assessments, proposition and enforcement of industrial wastewater discharge standards
Ministry of Housing and Urban-Rural Development (MHURD)	Control and construction of municipal water supply systems, water saving, urban flood management, water use planning, as well as construction and administration of municipal wastewater treatment facilities
Ministry of Public Health (MoPH)	Responsible for ensuring the safety of municipal water supply services (in conjunction with MHURD and MEP), formulating and enforcement of national drinking water standards
National Development and Reform Commission (NDRC)	Macro-economic development policies, utility price policies and investment planning, administration of concessionary finance program for the urban water sector
Ministry of Finance (MoF)	Management of national governments financial resources, budget allocations, and supervision of the country's financial system

The governance of urban water services involves many different government agencies with partially overlapping functions. The conflict between the Ministry of Water Resources (MWR) and the Ministry of Housing and Rural-Urban Development (MHURD) is a major concern in urban water management that was expressed by various experts. The Ministry of Public Health (MoPH) is responsible for drinking water quality and together with the Standard Administration issues the respective national standards that must be met by urban suppliers. The National Development and Reform Commission (NDRC) provides overall development policy and financial supervision to the urban water sector and (in conjunction with the MoF) administers the most important concessionary finance program.

This coordination problem is further amplified as the institutional division of responsibilities at the national level is reflected in equivalent line agencies at each of the lower levels of government. Each agency reports to both their political leader at the same level, as well as the agencies above them. And each agency monitors agencies below them. A selection of water-relevant agencies on the provincial level is listed in Table 4.

Table 4: Provincial-level agencies involved in the Chinese urban water sector

Agency	Responsibilities for the Urban Water Sector
Provincial Water Resources Department	Management of regional water resource infrastructure, allocation of water resources within province
Provincial Environmental Protection Bureau	Approval of environmental impact assessments, monitoring and enforcement of discharge standards, development of water quality improvement plans
Provincial Construction Department	Supervision of municipal utilities
Provincial Public Health Department	Monitoring and enforcement of drinking water quality
Provincial Development and Reform Commission	Approval of large investment projects
Provincial Price Department	Approval of municipal tariff adjustments

The Water Law is the most fundamental and comprehensive law of water governance in China. It was first promulgated in 1988, later revised and amended in 2002. The 1988 Water Law marked a fundamental change both in water policy and water administration as it set up a series of new water resource management systems, such as water supply and demand planning, water use permits, and water use charges.

Later, the 1988 Water Law was criticized for its emphasis on water exploitation over water saving and on economic benefit over environmental protection, the lack of implementing river basin management, and the incomplete implementation of water rights. The amendment of the Water Law in 2002 emphasizes demand management and water quality protection and thus paved the way for a transition from a focus on infrastructure development to a phase where more attention is being devoted to the management and protection of water resources.

The historic 2000 State Council Directive „Circular on Strengthening Urban Water Supply, Water Saving, and Water Pollution Prevention and Control“ set the agenda for the urban water sector for 2000-2010. It triggered the pricing reforms for water supply and wastewater treatment and promoted the conversion of the water sector from a state-planned to a market-driven sector. The 2004 State Council Notice on Promoting Water Tariff Reform, Promoting Water Saving, and Protecting Water Resource was another important step in this direction.

In 2006, the Ministry of Construction and the Ministry of Science and Technology jointly issued a Technical Policy to promote technology development and application of wastewater reclamation and reuse. The development target set by the Policy includes the direct utilization of reclaimed water for 10% to 15% of urban wastewater volume in northern water shortage cities and for 5% to 10% in southern water shortage cities by 2010. These figures increase to 20 to 25% in northern water shortage cities and 10 to 15 % in southern water shortage cities by 2015.

In 2006, the State Council presented the National Program 2006-2020 for the Development of Science and Technology in the Medium and Long Term (MLP) that aims to strengthen China’s scientific and technological progress. The MLP reflects China’s determination both to overcome growing domestic social and environmental problems through technology and to become a world leader in innovation. One of the ultimate goals of the plan is to develop technologies related to water resources and environmental protection. In the MLP the Chinese government allocates a considerable portion of its R&D investments on a limited number of research areas of which water supply and wastewater systems are part. Among the sixteen key projects to be launched the development of water purification technologies ranks prominently.

Table 5: Laws, regulations and policies for the urban water sector in China

Year	Title	Level	Significance for the urban water sector
1984 (1996)	Law on Water Pollution Prevention and Control (amended in 1996)	National Law	Legal foundation for water pollution control, requirement for cities to provide centralized wastewater treatment
1988 (2002)	Water Resource Law (amended in 2002)	National Law	General principles of water resource management: user-pays-principle, water conservation, integration of water quality considerations
1989	Environmental Protection Law	National Law	Includes water environmental protection regulations
1999	Improve Wastewater Collection Capability and Establish Sound Collection and Treatment Practices	NDRC, MoC, SEPA	Cities have to establish wastewater companies, collect wastewater fees as part of the water supply bill, and start constructing wastewater treatment plants
2000	Circular on Strengthening Urban Water Supply, Water Saving, and Water Pollution Prevention and Control	State Council Policy	Enforcement of the Law on Water Pollution Prevention and Control; agenda setting for the period 2000-2010 (60% urban wastewater treatment by 2010); market-oriented tariff reforms
2002	Circular on Accelerating the Marketization of Urban Utilities	MoC	Promotion of private sector participation through a variety of ownership arrangements
2002	Circular on Accelerating the Commercialization of Urban Wastewater and Solid Waste Treatment	MoC, NDRC, SEPA	Promotion of arrangements as build-operate-transfer, joint-venture with municipalities, and transfer-own-transfer
2004	Decision on Reforming the Investment System	State Council Policy	Allowance of nongovernmental entities to invest in municipal public utilities
2004	Management Maesures for Concession of Public Utilities	MoC	Basic rules for competitive and transparent awards of public utility concessions
2005	Strengthening Monitoring on Municipal Public Utilities	MoC	Supervisory role of municipal and provincial governments
2006	Technical Policy for Wastewater Reclamation and Reuse	MoC, MST	Guidance for regional water reuse plans, facility construction, operation and management, technical research

			and application, accelerating the sustainable utilization and protection of urban water resources
2006	National Program 2006-2020 for the Development of Science and Technology in the Medium and Long Term (MLP)	State Council Policy	Innovation as a new national strategy; making China an innovation-oriented country by 2020; development of technologies related to water resources and environmental protection

Source: Browder (2007), Khan & Liu (2008)

In regard of the large population and the fact that no municipal wastewater treatment plant existed in China in 1980, water management in China has proven to be successful to some degree. The treatment percentage of China's urban wastewater volume rose from 23% in 1995 to 63% in 2007, according to official statistics (MoHURD 2008). Additionally, the pollution loads have decreased due to municipal and industrial wastewater pollution control. On the other hand, the year 2008 saw 42 percent or about 242 million of the Chinese urban population without access to improved sanitation facilities (JMP 2010) and only about one third of the urban population connected to a wastewater treatment plant (OECD 2007). The latter fact that many more people have access to improved sanitation than are connected to wastewater treatment, while in other cases water treatment plants are idle since they do not receive any wastewater, also sheds some light on existing institutional inefficiencies, in particular the difficulty to coordinate those many institutions involved in (waste)water management.

3.2.3 More specific policies in favor of MBR technology

Effective regulation can be a major driver for the diffusion of eco-innovations which, due to their partly public good character, would not be provided by the market (Beise and Rennings 2005). Especially in China, however, the effectiveness depends on the concurrence of policy implementation on the national and local level.

In China, regulation on the national level has gained a particularly strong impact on the widespread use of advanced wastewater reclamation technologies since the announcement of the “Technical policy on municipal water reclamation” in 2006 when the central government for the first time acknowledged water stress in the North and East of the country and thus prioritised the reclamation of wastewater. The policy set out guidelines on R&D, marketing and plant building activities to promote the use of wastewater reclamation facilities. In 2010, during the 11th FYP period (2006 – 2010) the "Catalogue of Environmental Protection Industry Equipment (Products) Encouraged by the State" thereby assigns MBR technology a preferential status for wastewater reuse technologies. During the current 12th FYP period (2011 - 2015) authorities are expected to provide another set of stringent policies and facilitating measures. As such, in January 2011 the highest political authority, the national State Council, announced an annual investment plan of RMB 800 billion (EUR 110 billion) to the whole water sector (representing a 50 percent increase from 2010) during the 12th FYP period and dedicated its Central Number One document solely to the problems around water (CGTI 2012). The policies set out there were extended by the Central Number Three document and the actual 12th FYP agenda. Out of these national plans those policies are reviewed in Table 6, which are considered to be highly relevant for a wider diffusion and development of MBR technology.

The above policies reveal a high priority for wastewater treatment and reclamation. With the narrowing quality gap between standards for discharge and reuse the overall incentive for wastewater reuse is considerably high. Altogether this should facilitate the diffusion of MBR reclamation technology. However, effective regulation and the resulting regulatory advantage not only require the existence of facilitating national policies but their implementation, enforcement and control on the local level. Like in other policy fields, weak implementation on the local level is also apparent in the water sector. In contrast to the U.S. or Europe where central governments set out minimum requirements which are then refined on a sub-national level taking into account local characteristics, the Chinese central government formulated its latest discharge standards rather uniformly based on the best available technology (BAT), which at the moment is MBR. However, due to large local differences and economic growth considerations which are still the most relevant for many local policy makers discharge standards were often not put into force (CGTI 2012). This is particularly evident in poorer North West China with a total MBR market size of only nine percent (Frost & Sullivan 2011b) but also in more developed East China such as revealed by a recent Greenpeace investigation (China.org.cn 2012). It showed that companies still have large incentives to illegally discharge unprocessed wastewater while local authorities often do not want to, or cannot inspect the companies' activities. Another example was the national target set out in the 10th FYP (2001 – 2006) to construct thousands of new WWTPs. By the end of 2006 a study revealed that half of them did not work properly or were not even commissioned (Gleick 2009). Frequent reasons were corrupt local governments that desire to sustain uncontrolled economic growth or authorities that are constrained by inadequate budgets that hinder proper monitoring and enforcement. Central authorities are aware of these issues and introduced measures to overcome the lack on a local level, such as through the implementation of penalties such as fines of up to RMB 100,000 or production halts for companies and introduction of key performance indicators (KPI) to evaluate and promote government officials not only on the basis of economic performance.

Table 6: Overview on recent Chinese national policies in favor of MBR technology

	Description	Implications for MBR technology
Water consumption	Introduction of a threshold of 670 billion m^3 of national annual water consumption by 2020 and 700 billion m^3 by 2030 as well as a reduction by 30 percent in water intensity per unit of GDP and industrial output.	Considering the consumption of 599 billion m^3 in 2010 it shows the high demand for water conservation and water reclamation to remain below the threshold. Thus, policy supports the application of MBRs for wastewater reclamation.
Water pollution control	Identification of 9 highly polluting industries and introduction of new stringent discharge standards such as the "Discharge Standard of Water Pollutants for Pulp and Paper Industry" which is stricter than most U.S. or EU standards (Li et al. 2012).	MBRs could be adopted in industrial applications to meet the new discharge standards and to reclaim valuable substances that can be feed back into the production process.
	Introduction of the Grade 1 level A and B discharging standards in the municipal sector by the Ministry of Environmental Protection in December 2002. Large cities and municipalities are required to meet grade A whilst plants in lower-tier regions are required to meet level 1B.	Most of the existing municipal WWTPs need to be retrofitted in order to meet the new standards which are comparable with western standards. Since previous experiences with large-scale municipal MBRs have been positive it is expected that MBR will win the tender for retrofitting the WWTPs.
Water tariffs	In China, water tariffs for industrial users are generally much higher than those for domestic users and have increased by 9 percent annually over the last decade. Thus, it is expected that they will in-	Freshwater prices that are higher than prices for reused water are likely to increase the incentive for industrial users to either invest in decentralised MBR treatment plants for self-operation or buy recycled water from the municipal

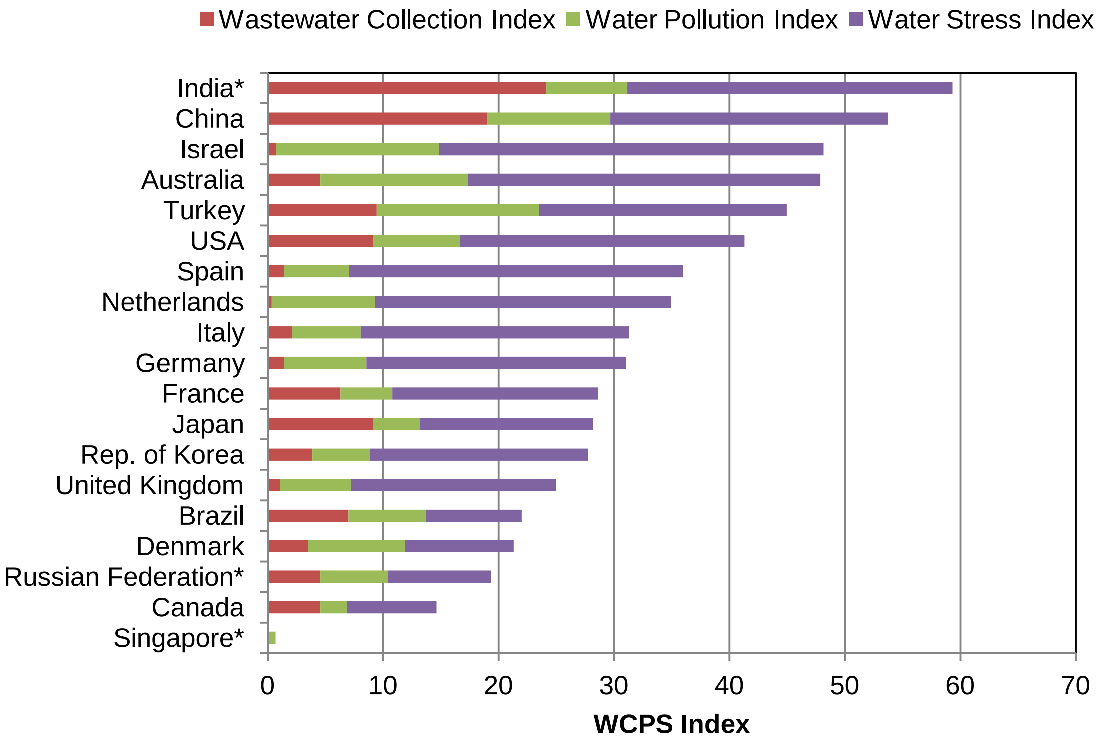
	crease further during the 12th FYP period.	sector.
Operation	Users of reclaimed water are compensated by 0.5 RMB/ton.	Compensation is expected to increase decentralized MBR adoption as an advanced reclamation technology.
Wastewater treatment and reclamation rate	By 2015, 20 - 25 percent of the municipal wastewater in the Northern cities should be reclaimed respectively 10 - 15 percent in Southern cities as defined by the Ministry of Environmental Protection.	Increasing reclamation targets strongly incentivise the use of MBRs in the municipal sector.

Source: CGTI (2012); Frost & Sullivan (2011b)

3.3 Conclusions

With regard to the natural and physical conditions, the need to use MBR technology appears to be much more urgent in China than in Brazil. Compared to Brazil, seven times as many Chinese share one twentieth of the water (as available per capita). Additionally, many of China's available water sources are much more polluted since, not the least, the wastewater of a much larger number of people is cleaned more poorly. These arguments are summarized in three different indicators, which are depicted for Brazil, China and a series of other countries in Figure 6. For China, which ranks second, the index is 2.5 times larger than for Brazil, which is fourth but last. Accordingly, the need to properly clean and reuse water is much greater in China.

Figure 6: Nationwide demand for MBR technology approximated by the composed WCPS Index

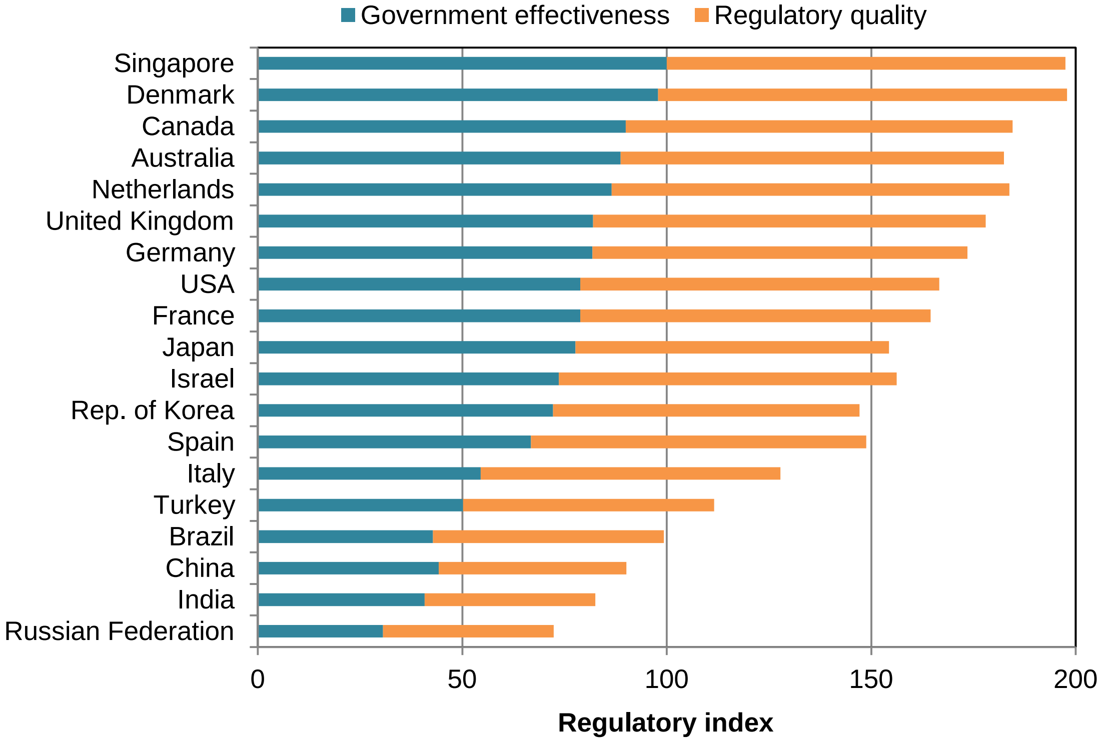


Notes: For India and Russia no data were available on the population connected to wastewater collecting system. Instead the indicator population with access to sanitation from EPI (2010c) was used. For Singapore the low score is explained by missing data on water stress and a zero score on wastewater collection due to 100 percent of population already connected to public sewerage.

Source: United Nations (2011); OECD (2012); EPI (2010c).

In the course of their development during the past half century, Brazil and China recognized the need to supply to their population clean water and safe sanitation. This is clearly documented in a series of legal institutions, which have been enacted in the meantime. To some extent, this legislation succeeded in meeting the basic needs. However, altogether the effectiveness is limited by governing and regulatory deficits, which are common to both, Brazil and China. This is also evident in Figure 7, where Brazil and China rank rather low.

Figure 7: Estimation of regulation enforcements for selected countries.



Source: GII (2012)

Although a general lack of central policy implementation can be identified, there are at least eleven Northern cities in China whose regulation of wastewater treatment increasingly enforces wastewater reuse technologies (Peng 2012). Amongst the pioneering cities for water reuse are Shenzhen and Beijing. Shenzhen aims to increase its wastewater reclamation rate from 11 percent in 2009 to 80 percent in 2020 (ADB 2012), Beijing, the world's water scarcest city, aims at reaching 70 percent by 2015 after 50 percent in 2010. In order to fulfil this target all wastewater treatment plants should be upgraded to wastewater reuse plants (Peng 2012).

4 Absorptive capacity

Among other influencing factors, the adoption of a new technology in a country depends on the capability of its inhabitants to operate the respective facilities. Going one step further and interpreting adoption as a country's capability to (contribute to) design and construct the devices, this implies that the country is endowed with the corresponding research facilities – in the form of public and private research institutes as well as R&D-conducting companies. Most effectively, these institutions or people work together in networks. How effective they are doing research, after all, can be assessed for instance by means of patent applications.

4.1 Research and innovation

Brazil

In 2001, the Brazilian government created the instrument of sectoral funds to channel industry-generated revenues into R&D in order to promote technological development and innovation. Each fund has its own research objectives ranging from fundamental investigation to commercial innovation. The program consists of twelve thematic and two transversal funds, of which one (CT-Hidro) is dedicated to R&D in water resources and water management. This fund is steered by the Ministry of Science and Technology (MST) in a committee with the National Water Agency (ANA), the Water Secretary, the Energy Secretary, the research funding agency FINEP, the National Science Council CNPq, and representatives from the private and scientific community. The scheme was successfully introduced to overcome instabilities in government spending on R&D which characterized the 1990s, and to inject large amounts of money into the Brazilian research and innovation system.

The Program for Research in Basic Sanitation (PROSAB) is the major research program in the Brazilian water and sanitation sector. The focus of the program is on developing and improving water treatment and sanitation technologies on the basis of priority research themes and research networks involving universities, technology institutes and private sector. Its main objective is to foster R&D in technologies of water supply, wastewater and solid waste that are easily applicable, have low costs of implementation, operation and maintenance and have the potential of improving the living conditions especially of the poor. According to Furtado et al. (2005), the PROSAB program has brought important structural changes within the research sector such as, for instance, the formation of academic networks of water-related research, the creation of the corresponding research infrastructure and the building-up of human resources. The most important research institutions in the field of water supply and sanitation systems are listed in Table 8. Additionally, it was confirmed by several interviewees that research on membrane-based water supply and wastewater treatment is conducted in several university institutes in Brazil.

Table 7: National-level agencies for research and innovation in Brazil

Agency	Importance for water and wastewater technologies
Ministry of Science and Technology (MST)	National science and technology policy
Research Funding Agency (FINEP)	Main agency for funding research in the business sector, offers grants and loans throughout every stage of the innovation process, supports the sanitation research programme PROSAB
National Science Council (CNPq)	Foundation linked to the MST, supports research through individual grants or research projects and contributes directly to the training of researchers

Table 8: Brazilian research organizations for water supply and wastewater systems

Research institute / University	Department
Federal University of Rio Grande do Sul	Hydraulic Research Institute (IPH/UFRGS)
State University of São Paulo	Hydraulic Technological Foundation Centre (FCTH/USP)
University of Brasília	Department of Civil Engineering, Programme for Environmental Technology and Hydric Resources (DE/UnB)
Catholic University of Brasília	Programme of Environmental Planning and Management (PPGA/UCB)
Federal University of Campina Grande	Programme of Post-Graduation in Civil and Environmental Engineering (UFCG)
Federal University of Minas Gerais	Engineering Department for Sanitation and Environmental Technology (DESA/UFMG)
Fed. University of Rio de Janeiro	Institute Alberto Luiz Coimbra (COPPE/UFRJ)

China

The largest research organization in China is the Chinese Academy of Science (CAS). It runs a nationwide system of over 100 research institutes and a prestigious research university. Research funding at the institute level is a combination coming from CAS, the Ministry of Science and Technology (MST) and the National Science Foundation of China (NSFC). Chinese R&D policy places a strong emphasis on innovation and the commercialization of R&D results.

Table 9: National-level agencies for research and innovation

Agency	Importance for water and wastewater technologies
Ministry of Science and Technology (MST)	Provides guidance and funds for major national S&T programs
National Science Foundation of China (NSFC)	Funds peer-reviewed basic and applied research in natural science fields, including research on water resource management for a resource-economical society
Chinese Academy of Science (CAS)	Largest research organization with more than 100 research institutes and a prestigious research university.

Table 10: Leading water-related research organizations in China

Research institute / university	
Tsinghua University, Department of Environmental Science and Engineering	Chongqing University
Tongji University	Central and Southern China Municipal Engineering Design and Research Institute
Haerbin Institute of Technology	Beijing General Municipal Engineering Design and Research Institute
China Institute of Water Resources and Hydropower Research	Shanghai Municipal Engineering Design General Institute

4.2 MBR-related research networks

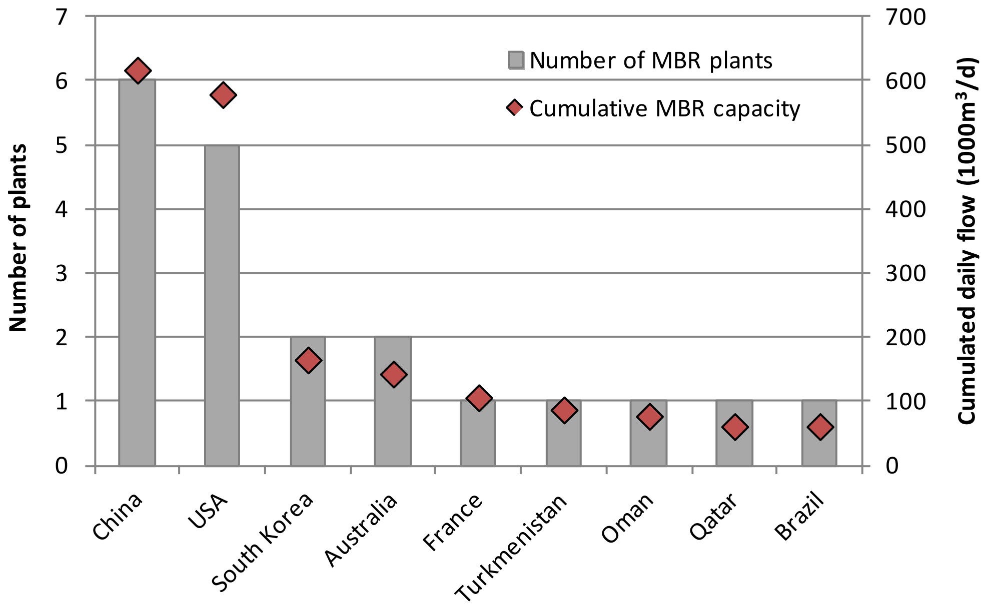
In contrast to the global perspective (see below) a national view reveals indeed some network activities in China as shown by Binz (2008). In his work on decentralised MBR technology he concluded that a strong technical innovation system (TIS) for decentralised MBR in China cannot be identified although there is partly strong support by legislations as identified in sections 3.2.2 and 3.2.3 and a considerable number of firms as well as research institutions in that field (see section 4.1). However, these actors rather act isolated from each other in different niches. Yet the TIS for MBR is part of a larger more dynamic network for membrane wastewater treatment technology represented by the "Membrane Industry Association of China", which could possibly facilitate (semi-) decentralised MBR technology. However there are noteworthy obstructions. On the one hand, dominant actors from the wastewater treatment and construction sector facilitate and favour centralised treatment systems such as large-scale MBR plants that actually hinder the diffusion of decentralised solutions. On the other hand the Chinese TIS for membrane wastewater treatment technology is embedded within global technical innovation systems (Binz et al. 2012). Although in principle the Chinese TIS could benefit from global connectivity, Binz also identified trends indicating the adoption of the existing regime of centralised treatment from abroad.

4.3 Application of MBR technology and MBR-related companies

China

First interest in MBR technology in China emerged in the early 1990s with nationally funded lab-scale research projects (Zheng et al. 2010), predominantly at Tsing Hua University (Beijing), Zhejiang University (Hangzhou) and Tianjin University, all of which are located in the arid Northeast of the country. Between 1995 and 1998 the first pilot MBR plants were developed. From 2000 on first residential and industrial small-scale plants have been built with treatment capacities <100 m^3/d. These were soon followed by medium-scale systems in the municipal and industrial sector with capacities up to 1,000 m^3/d and first feasibility studies on large-scale plants exceeding capacities of 10,000 m^3/d. During the first decade of the new century many nowadays dominant domestic suppliers of MBR units entered the market, such as Beijing Origin Water Technology Company (BOW 2012) in 2001 or Shanghai SINAP Membrane Tech Co. Ltd. (Shanghai SINAP 2012) in 2008. Albeit MBR technology was initially seen as the preferred wastewater treatment and reclamation technology for small (semi-) decentralised applications such as in smaller communities, in the time since their first adoption in China in 1998, there was a strong trend towards large-scale plants (Zheng et al. 2010), for which the country has gained much international recognition. From 2006 onwards there was a rapid increase in large-scale systems with an average annual increase by 50 percent compared to around 12 percent globally (Judd and Judd 2011). In an international comparison China is the country with the largest number of large-scale MBR plants in 2012 (see Figure 8). Beijing Origin Water, like Mitsubishi Rayon, is supplier of two of these large plants (MBR Site 2012a). Within China, important domestic MBR suppliers are Origin Water for municipal plants and Motimo Membrane Inc. for industrial applications. The majority of MBR plants, however, come from Japan (Mitsubishi-Rayon, Asahi Kasei) (Zheng et al. 2010).

Figure 8: 20 largest MBR plants worldwide by country of installation in 2012



Source: MBR Site (2012b)

Although two thirds of the MBR turnover is caused in the municipal sector with its predominantly large-scale WWTPs, from a Chinese perspective, many of the large-scale MBRs can still be characterized as (semi-)decentralised, on-site treatment (Zheng et al. 2010). This is even more evident in the industrial sector where by 2007 84 MBR facilities were used for wastewater treatment especially in the petrochemical industry (with capacities of up to 25,000 m^3/day; Zheng et al. 2010) or in major industrial parks such as the "Yangtze River International Chemical Industrial Park" operating a plant with a capacity of 40,000 m^3/day (Frost & Sullivan 2011b).

Brazil

Brazil also appears in Figure 8 with its largest MBR plant with a capacity of around 60,000 m^3 per day, which is just one tenth of the cumulative capacity of the listed Chinese MBR plants. Beyond this large plant, the number and cumulative capacity of MBR plants in Brazil remains far behind the respective Chinese figures even if the large difference in the countries' size, population and economic performance is accounted for.

Also in contrast to China, the MBR plants installed in Brazil are made almost exclusively by manufactures from outside Brazil. There is only one Brazilian membrane manufacturer: PAM Membranas, a spin-off company of the federal university of Rio de Janeiro. But the membranes produced by this company are said to be of low quality; so, they are hardly used for the manufacture of MBR devices. Even foreign companies with subsidiaries in Brazil (e.g. Huber SE, see Table 11) assemble their MBR plants with membranes from abroad despite the strong incentives to do otherwise. One such incentive is the high import tariff used to protect domestic manufacturers against competitors from abroad. It doubles the price of foreign membranes and renders their MBR plants less attractive. The other incentive against the use of foreign membranes is the condition that public funding of sanitation devices is bound to a minimum limited content of domestic parts constituting the funded device (Strauch 2014). (Foreign) companies manufacturing MBR devices in Brazil try to offset this disadvantage by importing only the membranes and buying most other components in Brazil. But this is not easy because the technological gap existing for the membranes is said to also extend to other parts such as the biological components and the system-integrating parts. Thus project developers refrain from using membrane systems due to lack of experience and knowledge.

Table 11: Companies selling MBR plants in Brazil

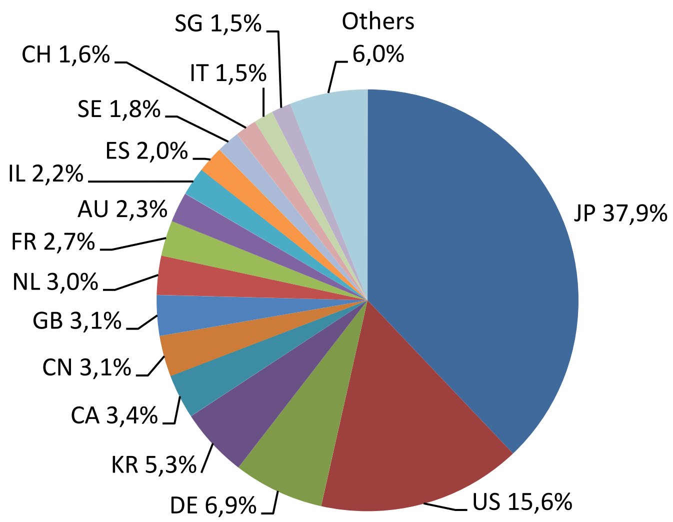
A3 water solutions GmbH	RWO GmbH Marine Water Technology
Aquantis GmbH	Saxonia BioTec GmbH
HUBER SE	STULZ-PLANAQUA GmbH
Koch Membrane Systems / Puron AG	WEHRLE Umwelt GmbH
MARTIN Systems AG (Astor)	newterra GmbH
MICRODYN-NADIR GmbH (Frings)	BUSSE IS GmbH

Source: Strauch (2014)

4.4 MBR-related patent applications

Beyond the existence of MBR-related research institutes and networks, a country's research performance and, therewith, its capacity to adopt and further develop a new technology in its own territory can be assessed on the basis of the numbers of patents applied for in a specific technology field. While the number of patent applications varies from field to field and depends on a variety of factors, it is still a good indicator for the intensity of research conducted in a country. As is shown in Figure 9, the countries with the highest shares, Japan, USA, Germany and Korea are those with the leading MBR suppliers. Although patenting activities in China started relatively late, this country has recently reached rank number 6 with a share of 3.1 percent for membrane-related patent applications.

Figure 9: National shares of worldwide patent applications related to semi-permeable membranes, cumulative figures for 2008 to 2011

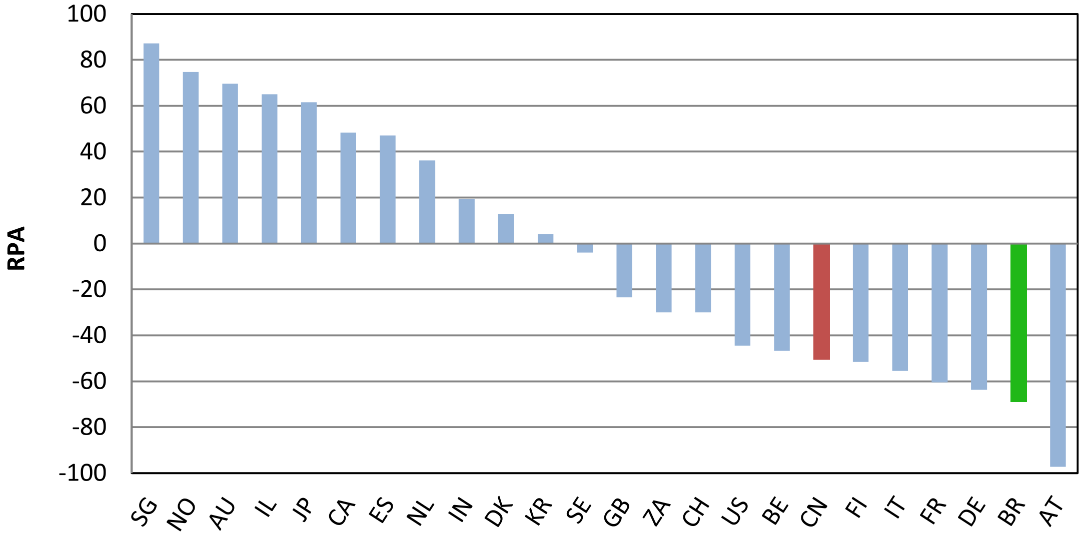


Source: PATSTAT database 2014, EPO and WIPO; analysis by Fraunhofer ISI

As Brazil exhibits a patent share of only 0.14 percent, its contribution is hardly detected. In order to find out, whether this may be due to Brazil representing a smaller economy with less patenting activity than most of the leading countries, another method is employed, which measures patent specialization, i.e. the ratio between a country's share of patents related to a specific technology field and the respective worldwide share. This indicator, the relative patent advantage, RPA, ranges between 100 (full specialization) and -100 (no patents at all) with 0 indicating average specialization.

Figure 10 shows the corresponding RPA values for Brazil, China and a series of other countries.

Figure 10: Patent specialization of Brazil, China and other countries for the field of semi-permeable membranes, assessed as relative patent advantage (RPA)



Note: RPA relates a country's patent share in one technology to its share in all patents;[11] application numbers are cumulative 2008 to 2011 data.

Source: PATSTAT database 2014, EPO and WIPO; analysis by Fraunhofer ISI

Most countries leading the RPA ranking have a close relationship to water recovery from wastewater or sea water, most prominently Singapore, which recovers more than one third of its drinking water, and most but not all of them (e.g. Japan) are relatively small economies. Conversely, large economies such as the USA and Germany show rather low RPA values and the same is true for China. Remarkably, Brazil exhibits an even lower value indicating that its low patenting performance is not due to its being a not so strong economy.

4.5 MBR technology design standards

At this moment in time, technological standards for MBR systems do not exist and each supplier provides its own idiosyncratic solution. Thus, MBR components are not compatible with each other, leading to possible lock-in effects with a certain supplier. The problem is widely acknowledged (Kraemer et al. 2012) and efforts are made to create networks such as the European MBR-Network (MBR Network 2012), which strive for the definition of common standards. Yet

11 The RPA ranges from -100 (no patents in the technology field) to 100 (complete specialization in the technology; RPA = 0 indicates the same share for both the specific technology and all patents (average specialization).

not Europe but China might be the first country to pursue comprehensive technology design standards. First national design criteria for MBR systems were defined by the Catalogue of Environmental Protection Industry Equipment in 2007, which put the focus on water quality aspects. In 2010 they were extended by a new set of criteria that changed the focus away from demand aspects towards competitive aspects of cost-effectiveness and energy efficiency (see Table 12).

Table 12: Excerpt of national MBR key design requirements in China

Key requirements in Edition 2007	Key requirements in Edition 2010
Influent water quality: COD<400 mg/l, BOD5<200 mg/l, pH 6~9, NH3-N<20 mg/l.	Treatment capacity per membrane unit of 325 to 1000 tons/d.
Operation flux > 120 L/m2hm, water recycling rate > 95 percent.	Operation lifetime for FS membranes >8 years and for HF membranes > 5 years.
Membrane and system operation lifetime >5 years.	Limit of energy consumption per ton of water treated < 0.5 kWh/ton
Discharged wastewater to meet the Standard for “Design Guidelines for Wastewater Reuse Project” (GB50335-2002).	Discharged wastewater quality to meet the Standard of Grade I Level A from “Municipal Wastewater Discharge Standard”. Reused wastewater quality to meet the “Standard for Reuse of Recycling Water for Urban Water Quality” and “Standard for Urban Miscellaneous Water Consumption”.

Source: (Frost & Sullivan 2011b)

Employing such comprehensive standards indicates an important step in the formation of China's own MBR innovation system, as these standards will focus the respective technology demand and the associated development in China on specific design characteristics. If suitable, these standards will thus not only give rise to increased economies of scale and learning effects; they will also render the technology design more attractive to potential users in other countries. In Brazil, the lack of relevance of MBR technology in research and in the market has so far failed to initiate such standardization activities as in China.

5 Relevance of different channels for transferring MBR technology to Brazil and China

5.1 Trade

As trade with and in particular imports from the technologically leading countries can represent an important channel for the transfer of MBR technology to Brazil and China, important respective trade figures and the most important import partner countries are listed in Table 13 and Table 14.

Table 13: MBR-related and total foreign trade of Brazil and China in 2011

Millions of USD	Brazil	China
MBR-related exports	68	1,166
MBR-related imports	198	2,100
Total exports	256,038	1,898,388
Total imports	226,243	1,743,394
RCA*	-83	-59
GDP	2,476,652	7,321,935

Note: Revealed Comparative Advantage is an indicator for the specialization of a country in foreign trade with specific goods (here: MBR-related).[12]

Sources: UN-Comtrade database, UN Statistics Division (2012)

In both countries, Brazil and China, MBR-related imports constitute about one tenth of a percent of total imports; in China a bit more (1.2 per mill) and in Brazil a bit less (0.9 per mill). This is close to the share of MBR-related from total imports worldwide (0.9 per mill). By contrast, MBR-related exports are much smaller. While, by definition, worldwide imports and exports must equal, MBR-related exports are only 35 and 55 percent, respectively, of the Brazilian and Chinese imports. This "negative" specialization indicated by the negative RPA values characterizes China and, even more, Brazil as technology importers with respect to MBR and, respectively, little or essentially no capacity to export its own MBR-related know-how to other countries.

12 The Revealed Comparative Advantage (RCA) relates a country's foreign trade ratio (export/import value) for a specific good/service to its total foreign trade ratio. The indicator is designed to range from -100 (no export of the specific good) to +100 (only exports and no imports of this good). 0 indicates trade with the good showing the same balance as total trade.

Table 14: Top-10 countries of origin of MBR-related imports of Brazil and China in 2011

Imports to Brazil	Share (%)	Imports to China	Share (%)
Argentina	21,4	Japan	28,3
USA	20,8	Rep. of Korea	12,5
Germany	6,8	USA	10,1
Belgium	6,5	Germany	6,0
Peru	4,5	Singapore	5,8
Chile	4,1	Malaysia	1,4
Ecuador	4,0	France	1,2
Italy	3,9	Indonesia	1,0
Colombia	3,6	Italy	0,9
Mexico	3,5	Australia	0,9

Source: UN-Comtrade database

With regard to the potential flow of knowledge accompanying the import of MBR-related goods, Table 14 shows that Chinese imports are not only above the average (see above), but the first five of the top-10 countries of origin are also the leading manufacturers and operators of MBR facilities. In the case of Brazil, by contrast, only two, the USA and Germany, are among the top-10. Most other countries are from Latin America and it remains unclear which role they play in terms of technology transfer. Probably, they cannot serve as major sources of knowledge as they do not develop and manufacture MBR devices themselves.

5.2 Joint research

An important factor for joint research are research networks. The crucial question in this context is how well connected the relevant actors are in order to effectively benefit from the knowledge shared between these actors. Actors connected with each other within a network constitute a major advantage in developing and using a specific technology. A strong network is more likely to provide a strong argument in favour of, to allocate the important financial resources for a widespread diffusion of, and to create a common vision for the future development of MBR technology. On a global level the most important and most vital networks for membrane sciences and MBR technology are the American Membrane Technology Association (AMTA), the UNESCO Centre for membrane science and technology coordinated by Australia, Membrane-Based Desalination: An Integrated Approach (MEDINA) coordinated by Italy, the Singapore Membrane Technology Centre and the European MBR networks AMADEUS as well as EUROMBRA coordinated by Germany (Yi and Shi 2012). These networks can be considered the places where much of the MBR development and research is taking place. With respect to the participating companies and institutions both Brazilian and Chinese actors are at least not directly part of these clusters and as such not represented in the membership structures. The inclusion of a Brazilian manufacturer or research institution is even less likely than in the case of China, as there is only one Brazilian company producing membranes of, according to our interviewees, poor quality. So, its capability to join an international network is even more limited.

Co-patents could be another specific expression of transfer of technology knowhow from whichever donor countries to Brazil and China. Co-patenting means that the patented research has been done jointly by researchers from two or more countries and, therefore, the application is also done jointly by people or companies from both countries. Conducting a corresponding analysis in our Patstat database it is found that, there is not any co-patent with a Brazilian or Chinese partner, which confirms the lack of Chinese connections to international networks stated above.

5.3 Foreign direct investments and Joint-Ventures

Companies from abroad wishing to sell MBR plants in Brazil or China basically got three alternative choices to do so. They could, first, produce in their home country and export the devices to customers in the other country. Evidently, the large distance between manufacturer and customer does not only make it difficult for the latter to learn about the former and his products. With regard to the complexity of MBR plants and their operation, it would also be difficult to ensure a proper operation and maintenance of MBR over this distance.

Therefore, foreign manufacturers are usually looking for a counterpart representing it in the partner country. This could, second, be a subsidiary of this company or, third, another company in a related business, which is well established in the partner country and willing to adopt MBR devices in its product portfolio. The subsidiary has got the advantage of allowing the manufacturer to keep control over their technology over the major part of the production chain. On the other hand, establishing the subsidiary in the receiving country implies substantial effort for establishing contacts to potential customers and mobilizing the necessary resources. This approach is basically the more promising, the smaller the cultural distance between them. Moreover, as the deployment of MBR technology often relies on funding by the government, most governments are not keen to support foreign companies at the expense of their own companies. In this case study, we got to see different ways how to deal with this trade-off. In both cases, Huber SE is the company on the German side. In Brazil, Huber has established a subsidiary which only sells the Huber products. Manufacturing in Brazil does not make sense as the market is yet too small. According to the interviewee, it took several years to establish Huber in the Brazilian market. A major difficulty faced by Huber is the import tariff imposed on all imported membrane-related products, which is intended to protect the one Brazilian membrane manufacturer PAM Membranas. As this tariff raises the price of the imports by a factor of two, Huber does not import entire plants, but only the membranes. The other parts are bought from and assembled by Brazilian firms on the basis of Huber know-how.

China, by contrast, is a very large market, where it makes sense for an exporting country to install its own manufacturing capacity. Therefore, the Huber subsidiary in China also manufactures wastewater treatment equipment. But the size of the Chinese market is not the only reason for doing so. Another reason is the reluctance of the Chinese government to support foreign companies, if Chinese companies also do the job (see section 4.3). A way out of this restriction for foreign manufacturers is to build-up their own production facilities in China and employ Chinese workers, which qualifies the production facility as domestic from the Chinese point of view. Like in Brazil, there is a limitation of the share of foreign content in technologies that are to be subsidized by the Chinese government. While the strategy in Brazil was to import only the membranes and have the remainder assemble by Brazilian companies, relocation of the manufacturing facility to China automatically renders all parts of Chinese origin.

Due to the regulation of foreign content, the other strategy, searching for a Brazilian or Chinese partner selling MBR devices in their respective countries is a more difficult approach. The manufacturer adopting this approach constantly faces a substantial competitive disadvantage. Nevertheless, we could identify one adopter of this strategy in Brazil.

The final approach, and usually the one most favored by the government of the receiving country, is the establishment of joint-ventures. By combining the powers of a foreign and a domestic company, a joint venture is a combination of the preceding two approaches. With respect to MBR, this would rather work for China with its potent domestic MBR-related companies than for Brazil (where the only one membrane manufacturer sells minor quality). However, no joint-venture in the field of MBR could be identified. The reason for this failure may be closely related to its advantage from the import country perspective: a joint venture leads to a substantial knowledge transfer between both companies. And what is good for the receiving company (usually in the importing country) turns out to be bad for the donor company. In the worst case, if intellectual property rights are not obeyed, the receiving company could eventually acquire enough know-how to manufacture MBR devices on its own.

6 Conclusions

MBR is a technology that can give rise to better wastewater treatment and, thus, enables the more sustainable use of the resource water. Doing so, it can also be part of a strategy towards adaptation to climate change, because in the future climate change may lead to the more uneven distribution of natural water supply.

While MBR has been developed in developed countries, developing and emerging countries are foreseen to be harmed more seriously by climate change. Therefore, technology transfer would make sense from the viewpoint of the receiving countries. On the other hand, the donor countries could benefit from the corresponding expansion of their markets. The challenge, however, resides in the uneven distribution of resources between both parties – financial as well as knowhow-wise.

Accordingly and in conclusion of the arguments brought up in the preceding sections, the following drivers and barriers for the transfer of MBR technology can be identified. They differ partly with respect to both countries, Brazil and China. First the drivers:

- In large parts, China suffers from severe water stress with water consumption far exceeding water supply. Additionally, water use leaves the resource in a very bad condition and the attempts to improve the situation are as yet not very successful. In Brazil, which is basically rich of water, water stress is a more regionally limited phenomenon; it could however grow in the near future due to changes in climatic conditions in the most populous areas.
- With regard to the institutional, especially legal framework, both Brazil and China exhibit at least formally a quite sophisticated management structure for

their water supply. So they were able to install a healthy water supply and safe sanitation for a large part of their population.

- Especially on the higher policy levels China also acknowledges the poor condition of its water sources and enacts policy measures to improve the situation. In Brazil, the same applies, to a lower extent, for those regions (e.g. in the north-east or in São Paulo) where water supply is not safe.
- Research into wastewater treatment in general and MBR in particular exists in both, Brazil and China. The number of research institutes and, even more, the number of patent applications is much higher in China than in Brazil. This difference is only partly explained by the larger size of China.
- More intense research in China is reflected in the large number of companies covering all sections of the production chain from membranes to complete devices. In Brazil, by contrast, only one Brazilian membrane company exists.
- Although networking between MBR-related companies and research institutions within China and beyond seems to be weak, the relatively large number of installed plants may induce China to become the first country to develop and install a standard for membrane-based devices. Altogether, the latter three points document the strong absorptive capacity of China with respect to MBR.
- China is a large market for MBR with respect to supply and demand. It is also a competitive market. Altogether it appears to be large enough to attract MBR manufacturers from other countries. Competition is an issue, but foreign suppliers can offset their price disadvantage by better technological performance. After all, the fierce competition is also to the advantage of both, the Chinese companies as they are forced to improve their products, which in turn will strengthen their competitive position worldwide in the future, and the foreign companies, which learn to supply at a lower price.
- If technology transfer is to be successful and sustainable, it has to respect the interests of both, the donor and the recipient companies. Three transfer channels were discussed, each of which has its pros and cons. (1) If IPRs were well protected, the formation of joint-ventures would be the method of choice to bring about a rapid transfer of know-how (Unfortunately they are not in Brazil and in China; see below); (2) The foreign company can enter the market of the receiving country through a local subsidiary. Depending on the respective institutional conditions it can be favorable to have this subsidiary deploy its own manufacture (China) or to use it as coordinator for import, purchasing and assembling the parts by means of local companies (Brazil). The latter example is on the brink to (3) the use of a local partner company selling and providing service and maintenance for MBR devices.

The barriers are:

- While the basic institutional structure favors advancements in healthy water supply and safe sanitation, the implementation suffers from lax compliance and monitoring, mainly on the more local level. This argument applies as well to China with its five levels of administration as to Brazil with its general lack of compliance.
- Especially in China, responsibilities are shared between a large number of organizations (e.g. ministries and agencies), which are often not well coordinated. As a result, measures in different policy areas often compromise each other with regard to effectiveness and, even more, efficiency. This may lead to the fact that the effluent of MBR is not used according to its potential.
- The low number of MBR-related research institutes, their low number of patent applications and the existence of only one relevant company indicates that the absorptive capacity for MBR in Brazil is rather small.
- While, eventually, the demand for MBR technology in Brazil turns out to be rather low, the market is further impeded by the import tariff on membranes, which is intended to protect Brazil's one and only membrane manufacturer and raises the membrane price twofold with respect to the global market. This renders MBR plants even more expensive and less attractive. As a consequence, competition, but also the market potential is low. This is considered as another severe limitation of technology transfer to Brazil. (In China, a high import tariff exists as well, but this barrier is overcome by donor countries by establishing their own production line.)
- As MBR is a wastewater treatment and water recovery technology, the water price in the receiving country is an important reference point. If fresh water is supplied at too low a price, MBR has got no chance to become competitive. This barrier is at least partly effective in both Brazil and China.
- As channel of technology transfer, governments, especially in China, prefer joint-ventures, because they ensure the receiving country to benefit in terms of an increase in employment and a gain of knowhow. The latter point together with the difficulties to protect their IPRs in the host countries lets many companies abandon the establishment of a joint venture.
- The standards for wastewater treatment in Brazil are still low, and water scarcity problems are addressed more through large projects like dams and pipelines than through decentralized measures or efficiency gain. Thus the market for high end technology remains limited.

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Karlsruhe 2015