Lead market for membrane bio-reactor (MBR) technology – China's second-mover strategy for the development and exploitation of its lead market potential

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1 Introduction

With more than 1.3 billion inhabitants, China is the most populous country on earth. Many of those people including the residents of (e.g.) Beijing live in parts of the country that suffer from water scarcity, which leads to the over-exploitation of water sources, including ground and surface water. At the same time, the industrialization of China is continuously intensified especially in the densely populated regions leading not only to a further increase in water consumption, but also to the on-going pollution of the remaining water sources. 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).

In order to escape this aggravating situation, it is necessary to adopt a two-fold approach: avoid the pollution of water bodies, which are often sources of water supply, and reduce the amount of water withdrawn from the sources. Advanced wastewater treatment is the key to the solution of this problem, as it enables cleaning of the wastewater to such an extent that the water can be reused for various purposes. This does not only avoid the pollution of the existing water sources; it also saves this resource by reducing the withdrawal of water. The membrane bio-reactor (MBR) technology is such an advanced wastewater treatment approach exhibiting the additional advantage of a compact size. This would enable the extended application of this technology on-site in existing, dense settlements with little interference with the existing infrastructure (Binz 2008).

Like many other end-of-pipe environmental technologies, the treatment of wastewater by MBR leads to the internalization of substantial cost, which is borne by the economy. In order not to hamper growth and employment, this cost has to be kept as low as possible. One approach to the reduction of this cost in the longer term could be the formation of a lead market for this environmental technology. According to the lead market concept (Beise 2001; Beise 2004), the extensive development and employment a new, innovative technology in one country gives rise to cost decreases on the part of the domestic manufacturers and to improved performance, which is not only beneficial for the domestic users, but represents a competitive advantage in supplying this technology to other countries. If, under certain circumstances, this position is maintained over a longer period of time and the market for the original manufacturers extended many other countries, this is called a lead market. Making use of this lead market and selling the technology abroad may then reimburse at least one part of the money that has been spent for its original employment at home.

Now, the MBR technology is not quite a new technology. Although it was developed and employed in several industrial countries over several decades, it never occupied more than a market niche. By contrast, the water-related environmental challenges in China are so big and the country so large that both facts may indeed form the basis for more than a niche market. In this case, China would not be the first mover, but it would be the first country to create a real lead market.

This working paper will assess the potential for the formation of a lead market for MBR wastewater treatment plants in China. It will start with a description of the characteristics of the technology and its diffusion worldwide and in China in section 2. Section 3 will explain the lead market concept and describe in detail the factors that contribute to the formation of a lead market. In section 4, these factors will be assessed for the case of MBR in China, but also in other MBR-supplying countries. Eventually, the actual lead market potential is evaluated for China and other countries (in section 5) and recommendations for the formation of a lead market strategy are given (in section 6).

2 Technical background

2.1 Description of MBR technology and its environmental advantage

A membrane bioreactor (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. (2012) that treatment capacities below 50 and above 5000 person equivalents are as yet not cost-effective due to the inefficient down-scaling of larger plants;
- 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.

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[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.

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 it in the past.[2]
- If the MBR run-off is used for human health-sensitive 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 recipient 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.

In industry, the latter advantage is extended even more by the fact that MBR often enables the simultaneous recovery of both clean water and (some of) the chemicals polluting the water before the treatment. In many such cases, the yielded water is so clean that it is preferred for running the industrial process over other sources of water such as the drinking water provided by the municipality.

2.2 Diffusion of MBR technology

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

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[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).

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[3] in Japan as part of a government-funded research program at the end of the 1980s. The integration of 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 (see also Figure 11), 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). 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 1) 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.

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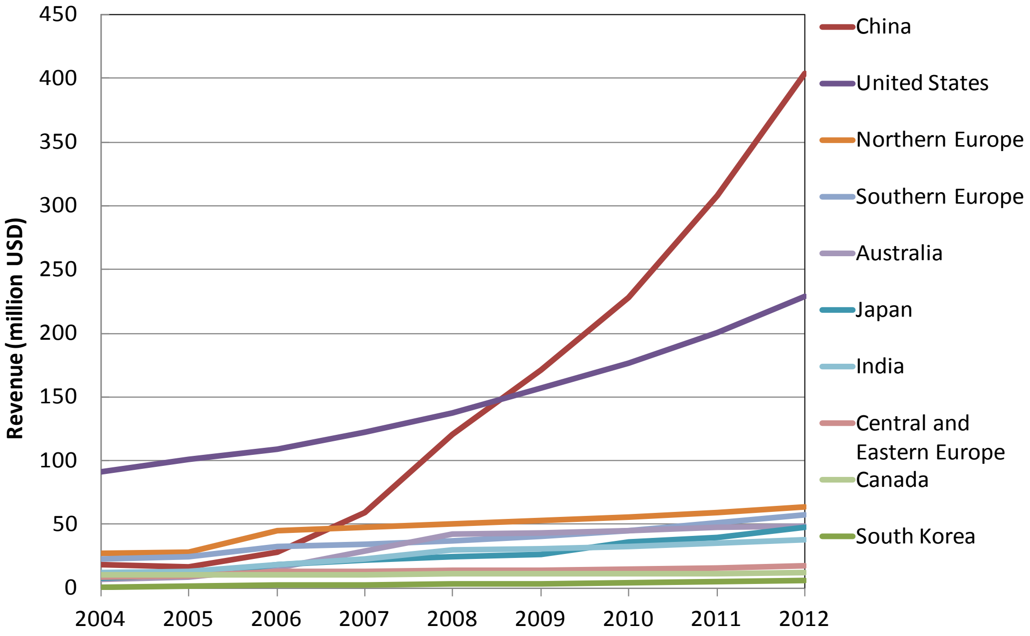
[3] Until then the standard MBR design was external MBR with the filtration unit located outside the wastewater treatment tank.

Figure 1: International diffusion of MBR technology approximated by sales trends

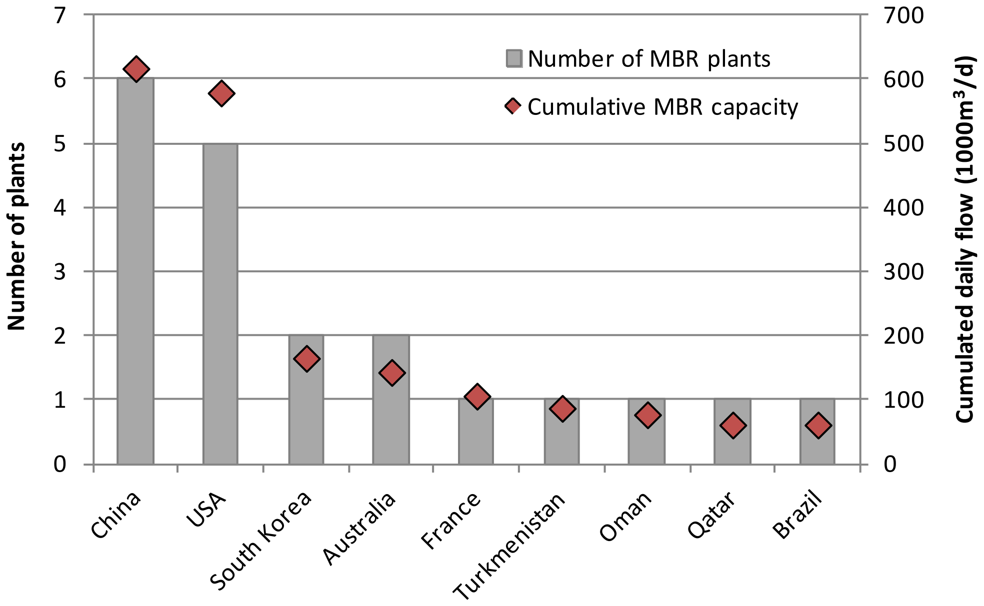


Source: Own calculations based on Frost & Sullivan (2008) and Frost & Sullivan (2011b)

In 2011, the global MBR market was estimated at USD 838.2 million and is projected to grow at a 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).

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), Zheijang 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 2). Beijing Origin Water, like Mitsubishi Rayon, is supplier of two of these large plants; the largest supplier worldwide, however, is General Electrics (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 2: 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 are 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).

3 Lead market concept and method

The lead market concept was first described by Beise (2001). It provides a theoretical framework to understand and explain the global diffusion of innovations and the determinants which constitute the potentials for a country to become the pioneering country, the “lead market”, for an innovation. The existence of a lead market for an innovation is highly beneficial for a country as the lead market significantly shapes the characteristics of an innovation and defines the global standards, which gives rise to a substantial competitive advantage (Gerybadze et al. 1997). Previous case studies on lead markets (Beise and Rennings 2003; Beise 2004; Beise and Rennings 2005) showed that the lead market often denotes the country in which a now globally dominant innovation had first been widely adopted before it was commercialised world-wide[4]. The reason for this is that the early adoption of an innovation allows firms to preserve their leading position by setting new technical standards, constantly improving their product solutions (learning-by-doing) and receiving valuable long-term user feedback (learning-by-using) as well as market knowledge. Prominent examples of actual or previous lead markets are the USA for information technology (NationMaster 2012a), Scandinavia for cellular mobile phone technology (NationMaster 2012b) or Japan for the ancient fax technology ((NationMaster 2012c). In order for an innovation design to become globally dominant, it often has to prevail over competing designs that provide the same function and are initially preferred in other countries. Over time the former wins the race on the world market and is widely adopted in “lag market” countries (Kotabe and Helsen 1998; Kalish, Mahajan, and Muller 1995). Thereby, the global success of a single innovation follows the argument that at a certain point in time the advantage of international standardisation overcompensates the variety of preferences in different countries, making the coexistence of several innovation designs obsolete. According to the lead market concept, the success of the international diffusion of a particular innovation design over other competing designs and the leading role of a country in designing these standards can be explained by nation-specific demand, market and supply-side conditions. The lead market concept refines them into a typology of seven interdependent lead market advantages[5]: (1) demand advantage, (2) price advantage, (3) regulatory

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[4] As Beise (2001) notes, the lead market does not have to comprise the country in which the innovation was initially invented. With regard to the examples mentioned below, none of them was invented in the country in which it took off first: The PC was first invented in France and cell phones as well as the fax machine were invented in the USA.

[5] The original typology of Beise (2001) contains five lead market advantages that were later extended by regulatory advantages (Beise and Rennings 2005) in order to account particularly for environmental innovations. In this case study we additionally include “supply-side advantage” to account for a country's technological performance.

advantage, (4) export advantage, (5) market structure advantage, (6) transfer advantage and (7) supply-side advantage. The more of these advantages can be identified for a specific innovation design in a given country, the higher the likelihood that this country forms the lead market for this innovation. The following subsections introduce each of the advantages in detail together with indicators that allow for an empirical assessment of the lead markets conditions with respect to MBR technology.

3.1 Demand advantage

A demand advantage comprises conditions on the national level and in the respective market, which promote the early adoption and further advancement of an innovation design that, due to its benefits, is likely to be adopted worldwide in the future. Once the beneficial characteristics are demanded in other countries as well, the early adopting country will be at the forefront of innovation and its companies will successfully compete within, and serve the markets in the other countries. For the MBR technology we argue that countries suffering simultaneously from water scarcity, water pollution and insufficient sewage treatment are now likely to engage in advanced wastewater treatment and extended water reclamation and therefore anticipate the future global demand for MBRs, giving rise to a demand advantage. In order to quantify the demand, a composed Wastewater collection, water pollution and stress (WCPS) Index is used as indicator for the demand advantage. The index is normalised in a range from 0 (lowest advantage) to 100 (highest advantage) with each of the sub-indicators having equal weight. Another indicator of a demand advantage is public acceptance. The more highly the benefits of a certain innovation design are acknowledged, the more likely this design will emerge as the preferred design on the national level and, once the benefits are recognized elsewhere, displace other designs existing abroad. Public support for MBR technology was approximated by a 2012 consumer survey on the public acceptance of reused wastewater (GE Power & Water 2012).

3.2 Price advantage

Price advantages refer to national conditions causing lower relative prices of an innovation design compared to innovation designs employed in other countries. In this context, price advantage does not so much refer to lower unit labour cost, lower cost of material inputs or a higher degree of externalization of (environmental) cost, as these advantages are easily overcome by competing countries with lower wages and lower social and environmental standards. By contrast, a price advantage can also consist in providing on the national level a niche with a high price environment in which the innovative technology can compete more easily and, by extending its capacity, learning by doing and realizing economies of scale, give rise to a price decrease (and subsequent increase in demand) on its own part. This type of price advantage is much more long-lasting as it is not easily caught up by other countries. Once the innovative technology has been established, the high-price niche is usually given up, because either the new technology itself experiences a decline of its price level or the prices in other countries increase and adjust to the domestic level (e.g. because prices or standards increase globally). Attracted by the relative price reductions of the innovative technology countries will then abandon their own designs in favour of the less cost-intensive design and give rise to its international diffusion. In the case of MBR factor price changes are approximated by membrane prices as an important input factor in the production. Thus, countries with low membrane prices have at least one price advantage in their production of MBRs.

3.3 Regulatory advantage

Demand and price advantages sufficiently explain the demand-oriented aspects for most of the innovations. Eco-innovations such as MBR, however, face an additional (double) externality problem (Rennings 2000) in that they reduce environmental harms such as water pollution but do not provide any or only low additional user benefit compared to conventional technology. Under these circumstances firms will have no incentive to invest and develop eco-innovations albeit in the long run they could gain a competitive advantage such as by increased efficiency for resources which are at least partly private goods (Porter and Van der Linde 1995). In this context a regulatory advantage refers to national conditions that prevent market failure arising from the externalisation of costs. They facilitate the development process of eco-innovations by providing a supportive environment through policy measures giving companies an incentive to develop and employ eco-innovations. To assess a regulatory advantage for MBR recent Chinese environmental water policies on both national and local levels are reviewed. Apart from the qualitative assessment a regulatory advantage is further approximated by a regulatory index composed of two indicators “Government Effectiveness” and “Regulatory Quality” (GII 2012). The reason behind is that the pure existence of environmental policies alone does not constitute an advantage unless these policies are properly enforced, controlled and monitored. Countries are ranked on a scale ranging from 0 (lowest regulatory advantage) to 100 (highest regulatory advantage).

Contrariwise, a regulatory disadvantage is constituted by the subsidization of the price paid for publicly supplied conventional water (abstracted from ground or surface water), as the MBR technology has to compete with this inexpensive water source. Countries reducing or phasing out this type of subsidy and further increasing the price of water in response to an anticipated water shortage at an early stage are more likely to avoid this disadvantage.

3.4 Transfer advantage

The transfer advantage responds to the question why and under which conditions a new technology developed in one country is adopted in another country and, later on, still produced in the country of origin and not in countries that adopted the technology later on. Accordingly, the transfer advantage comprises national conditions that support the transfer of the benefits of an innovation design perceived at home to other countries. The transfer advantage often consists of a high reputation of a country for a specific innovation. This can be done by adopting a successful future innovation at an early stage, an effect which is known as the demonstration effect of adoption (Mansfield 1968). Closely related to reputation is the visibility of a country for a specific technology on an international level which can be seen as another transfer advantage. Visibility of MBR technology was approximated by the Revealed Comparative Advantage (RCA),[6] an indicator for the specialization and, accordingly, international competitiveness of a country exporting the respective technology.

3.5 Export advantage

An export advantage comprises national conditions enabling a country to develop widely applicable innovation designs rather than idiosyncratic solutions and facilitating the adoption of a dominant domestic design in other countries. Such conditions are the inclusion and consideration of international demand preferences in the development process of own innovation design, which comprises the sensitivity for foreign problems and needs and is facilitated by the adoption of national conditions that are similar to conditions in many foreign countries. The closer two countries are with respect to their cultural, social, economic and environmental conditions, the more likely one of the two countries adopts the innovation design which was initially preferred by the other coun-

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[6] The RCA is calculated by relating the export-to-import (*E/I*) ratio of a country *i* for the specific innovative good *t* (here: MBR components such as membranes) to the respective ratio for all exported and imported commodities. The higher this ratio, the stronger is the performance of this country trading the innovative technology. In order to facilitate the comparison of the results the ratio is further transformed: $\mathrm{RCA} \quad = 100 * \tanh\left(\ln\left[\left(\frac{\mathrm{E_{i,t}}}{\mathrm{I_{i,t}}}\right) / \left(\frac{\mathrm{E_{i,all}}}{\mathrm{I_{i,all}}}\right)\right]\right)$. RCA is normalized to constrain the RCA values on a scale between -100 and 100. Values between -20 and +20 indicate no significant specialization. Values greater than +30 indicate a specialization in MBR exports and a comparative advantage of the respective country whereas values smaller than -30 indicate a comparative disadvantage.

try (Vernon 1979). For MBR technology, the similarity of national and global conditions was approximated by three environmental conditions, for which the specific national values were compared with the global average: water quality as measured by the Water Quality Index (EPI 2010a); percentage of territory suffering from water stress (EPI 2010b); and population connected to wastewater collection system (OECD 2012).[7] The underlying argument is that countries whose environmental conditions are similar to global conditions are more likely to develop MBR systems that can be operated worldwide. In order to actually measure the export orientation of companies of a given nationality and their sensitivity for foreign demand preferences, the export of water purifying systems (HS 2002 commodity code 842121; data from UN Comtrade 2011) of that country to its three main trading partners was compared with its total exports of this commodity. Countries with highly diversified export structure (i.e. a lower share going to the three most important partners) are more likely to develop and successfully export MBR systems than countries depending strongly on their three main trading partners.

3.6 Market structure advantage

The market structure advantage refers to conditions of the national market that increase the degree of competition. Previous case studies highlighted that the countries of origin of lead markets typically show high competitiveness. The logic behind this is that companies facing strong competition will have to deliver more and different innovation designs, i.e. they will have to invest more in the development of products, in order to find the most preferred design, which enables them to outcompete their rivals and gain a significant share of the global market. This raises the question as to which market structure is most suitable for bringing about a high degree of competition. On the one hand, new, small companies are considered a frequent source of innovations (e.g. Audretsch 1995) and the more of them there are, the more innovative designs will be created and compete with one another. On the other hand, many small companies may not be suited best to compete in foreign markets, because they are lacking the financial and human resources to enter those markets and bear the risks associated with selling its products in an unknown (market) environment. In order to estimate the market structure advantage for MBR technology the size and market shares of the MBR industry was chosen as an indicator to approximate market concentration. In order to collect information on suppliers of membranes, filtration modules and equipment as well as

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[7] While this set of indicators has been used already to demonstrate a possible demand advantage, it is used differently in the context of regulatory advantage. While its combined strength counts in the former case, its similarity with the respective indicators representing all other countries is relevant in the latter case.

process engineering companies and consulting firms an online search was conducted using six different databases (Alibaba 2012; Environmental Expert 2012; MBR Network 2012; MBR site 2012b; Tradekey 2012; Water & Wastewater Direct 2012). It is argued that in the beginning, when the basis for a lead market is formed in its respective country of origin, a large number of companies engaged in each of these fields indicates a more vital industry and a higher degree of competition putting pressure on companies to innovate. Later, when the lead market expands into other countries, companies have to be large enough to compete with other (potentially large) competitors in those foreign countries.

Beside these more quantitative figures, the specific types of actors involved and their interactions are at least as decisive for the innovativeness of a business as the number and size of the companies. This argument will be addressed in the following subsection.

3.7 Supply-side advantage

A supply-side advantage is constituted by national conditions that enable a country to actively develop innovations and guarantee advantages in technological performance in comparison to other countries. Traditional lead markets for an innovation have an abundance of knowledge resources as well as intellectual property rights and participate in technology clusters or technical innovation systems. That is, their industries are vital and the different actors are well interconnected with each other. The supply-side advantage for MBR technology is identified by the country's specialization in MBR specific patent applications (RPA) and literature (especially journal articles; RLA)[8] and its ranking on university-industry collaboration in R&D (WEF 2012), the state of cluster development (WEF 2012) and a qualitative review of the existing networks for membrane sciences and MBR technology. Additionally, reference is made to studies of Binz (2008) and Binz et al. (2012), which identify connections in terms of knowledge flows between related actors within and across countries.

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[8] $\mathrm{RPA_{hyp}} = 100 * \tanh\left(\ln\left[\left(\frac{\mathrm{P_{i,t}}}{\mathrm{P_{i,all}}}\right) / \left(\frac{\mathrm{P_{w,t}}}{\mathrm{P_{w,all}}}\right)\right]\right)$ relates the ratio of patents applied by a country *i* for a specific technology *t* over all patent applications of this country to the ratio of all worldwide patents for technology *t* over all patent applications worldwide. As with RCA, this ratio is normalized to yield values between -100 and 100 (See footnote 6).

RLA is determined analogously for the numbers of journal articles.

4 Assessment of the lead market potential

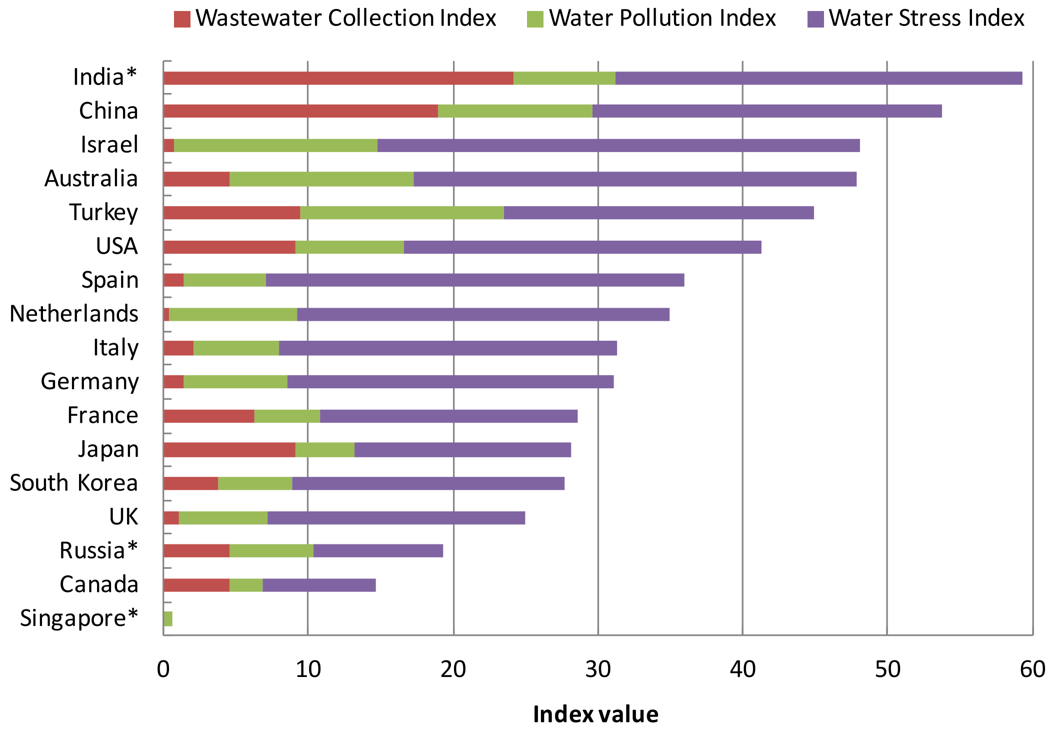
In the following subsections the seven lead market advantages from the lead market concept are assessed for membrane bioreactors as an eco-innovation design in wastewater treatment and reclamation in a cross-country comparison. First demand, price and regulatory advantages are identified in order to estimate the strength of demand-oriented factors. Then export, transfer, market structure and supply-side advantages are analysed to estimate the degree of supply-oriented factors that facilitate the development and production of (semi-) decentralised MBR technology. The selection of the countries for the cross-country comparison was based on different arguments. Canada, France, South Korea and Italy were included due to their strong research activities. Japan, like Germany and the USA, were included due to their first development, early adoption and (with the exception of Germany) current market dominance. Singapore was included due to its significant high level of water stress and the large policy incentives to overcome this problem by large-scale employment of membrane filtration (see NEWater project). Denmark was included due to its strong patent specialisation. The UK was included due to the significant size of its MBR industry. Turkey was added to the selection due to its export specialisation. Spain was considered due its operation of some of largest MBR plants in Europe. Similar to China, India, Russia and Israel were considered due to their high demand potentials; the last two representing significant growth markets as identified by the interview partners.

4.1 Demand advantage

As indicated by the WCPS index shown in Figure 3, recent Chinese dynamics for MBR technology can be explained by high demand as expressed by all three sub-indicators identified as important for the adoption of MBRs (see section 3.1). First, less than 50 percent of the population is connected to wastewater collecting systems, which is the second lowest value after India. Between 1996 and 2009 the total length of the urban pipeline network in thousands of kilometres increased by only 7 percent (Li 2011). This considerably low value indicates that in fact on-site water treatment might represent a promising option. Second, the quality of China's water resources is relatively poor with only Israel, Turkey and Australia facing poorer quality. Third, albeit local water stress in the Northern provinces of China is frequently mentioned as the most problematic issue, an international comparison reveals other countries facing significantly more water stress. In China around 20 percent of the territory suffers from water stress, which is relatively low compared to Israel with around 75 percent, Australia with 45 percent or even the USA with 21 percent. Thus, depending on the perceived relevance of each of the factors China's demand can be considered slightly higher or lower as shown by

Figure 3. Altogether the demand potential is considered to be high enough to constitute a substantial demand advantage.

Figure 3: National demand advantage 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 a zero score on wastewater collection due to 100 percent of population already connected to public sewerage and missing data on water stress. In fact, water stress should be quite high because the water sources in Singapore are not sufficient to cover the demand of all people and the economy.

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

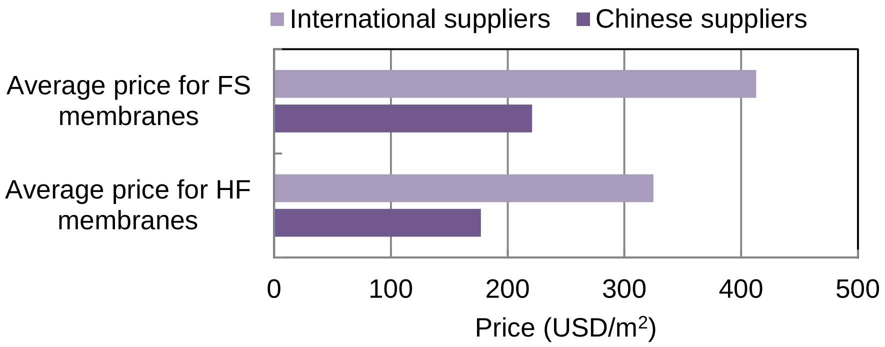
Another key for the adoption of MBRs, particularly in regions with high water stress such as China is the public acceptance and trust in the technology for water reuse applications (Beddow 2010a). The reuse potential in China is high as indicated by a wastewater reuse rate of only 8.5 percent in 2010 (Frost & Sullivan 2011b). A recent GE Water Survey (GE Power & Water 2012) reveals that in China citizens are well informed and aware of the origin of their water sources. In contrast to 69 percent in the USA and 85 percent in Singapore, 86 percent of the Chinese population know where their water comes from. Keeping in mind that due to its challenging water situation, Singapore is amongst the countries with the highest awareness and valuation of its water resources worldwide, the results for China indicate attitudes of general awareness and high public interest in water-related topics.

Apart from public awareness, China also shows strong trends of increased public support and private funding. Facilitated by effective government regulation (see section 5.3) market opportunities for the private sector arose across the whole water value chain, including the wastewater treatment sector. Evidence for this is provided by investments from private equity and venture capital funds increasing significantly from USD 50 million in 2010 to USD 400 million in the first four months of 2011 (CGTI 2012). Altogether China's demand advantage for MBR technology is clearly visible and to a high degree explains the country's rapid adoption of MBRs in the last decade.

4.2 Price advantage

Price advantage refers to national conditions that render the production and application of MBR technology in one country more inexpensive – and thereby more competitive – than in other countries. The rapid increase in the application of MBRs in China may be a good argument in favour of a price advantage for two reasons: on the one hand, many installed devices give rise to learning and scale effects and accordingly to lower costs, while, on the other hand, lower prices lead to an increased engagement of users in this technology. The effect of this self-enforcing mechanism on the price of membranes representing the most important component of MBR is shown in Figure 4. As Pearce (2008) points out, this is the combined result of significant price reductions and wider public acceptance, particularly in the municipal sector. Whatever the reasons are, Chinese membrane prices turn out to be almost 50 percent lower than the international average. This cost advantage was confirmed in two interviews of German MBR suppliers who attribute China very competitive prices for membranes and modules, however, often at the cost of lower quality especially in the case of the modules. Accordingly, the reputation of Chinese membrane modules was rather low and, at least until 2007, even the domestic market was still preferring foreign products (Frost & Sullivan 2011b; see also section 2.2).

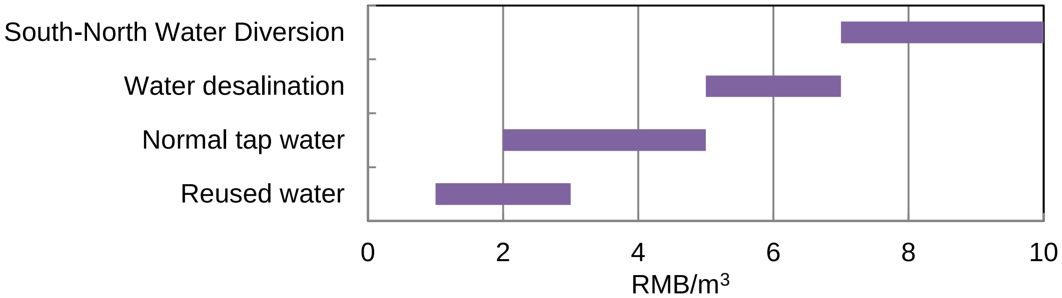
Figure 4: Chinese membrane prices in an international comparison.



Source: Frost & Sullivan (2011b).

Regardless of who is supplying the MBR plants (Chinese or foreign companies), another argument can be interpreted in terms of a price advantage for China. If the MBR technology is to be employed in large scale in China, its cost has to be borne, if not by the individual users, then by the government. But why should the Chinese government support what other countries do not? Because of the imminent water scarcity and the health-threatening water quality prevailing in large parts of China. From the economic perspective, therefore, the question is not whether MBR technology is to be applied, but whether this way of supplying water of sufficient quality to an increasing number of inhabitants in north-east China will turn out to be the least expensive. Figure 5 shows the estimated cost ranges for four alternative sources of future water supply in China. Interestingly, the cost of water reclamation from wastewater by means of MBR technology is with RMB 1 – 2.5 per cubic meter less expensive than the extraction of ordinary tap water from ground or surface waters, which costs RMB 2 – 5 per cubic meter. Not surprisingly, water desalination or the South-North Water Diversion are expected to be even more expensive. Even today, water reclaimed by MBR technology is economically more attractive in Northern Chinese cities such as Beijing or Tianjin, where nationwide the highest municipal water tariffs (around RMB 4 /m^3; CGTI 2012) are paid. So, owing to its special conditions in terms of water scarcity and the quality of available water sources, the north-eastern part of China apparently represents a niche market, which can be interpreted as a price advantage – not so much in terms of production cost and in absolute terms, but with regard to the opportunity cost of supply and the willingness to pay a premium for an improved water supply.

Figure 5: Cost ranges for different sources of water supply in China.



Source: Li (2011)

4.3 Regulatory advantage

Effective regulation can be a major driver for the diffusion of eco-innovations which, due to their partly public good character, would not have been 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.

National policy objectives …

In China, regulation on the national level has gained a particularly strong impact on the widespread use of advanced wastewater reclamation technologies owing to 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. Since then 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 Five-Years-Plan (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 water-related problems (CGTI 2012). The policies set out there were extended by the Central Number Three document and the actual 12th FYP agenda. From these national plans, those policies considered to be highly relevant for a wider diffusion and development of MBR technology are reviewed in Table 1.

Table 1: Overview on recent Chinese national policies in the water sector

	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 of 30 percent in water intensity per unit of GDP and industrial output.	Considering the consumption of 599 m^3 in 2010 it shows the high demand for water conservation and water reclamation to remain below the threshold. Thus, the 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.
	Discharge reductions for COD by 8 percent and ammonia nitrogen by 10 percent between 2011 and 2015. Further reduction of five heavy metals (arsenic, cadmium, lead, chromium,	MBRs can effectively reduce the amount of COD or ammonia nitrogen and reclaim heavy metals in the wastewater. Thus, the use of MBRs for wastewater treatment and reclamation

	mercury) from industry effluents by 15 percent based on 2007 levels.	is supported by this policy.
	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 increase further during the 12th FYP period.	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 sector.
Construction	The Chinese government is compensating for 50 percent of the total installation costs for municipal WWTPs.	Whilst MBR technology in general will possibly benefit, the compensation makes larger investments more attractive to largely benefit from economies of scales. Thus, most of the municipal WWTPs under current commission are clearly exceeding the capacity for decentralised treatment.
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	Increase of the wastewater treatment rate from currently 50 to 80 percent for localities and from 75 to 85 percent for cities.	Yet the lack of knowledge and expertise may hinder the adoption of MBRs in most of the rural areas regardless the new targets. Nonetheless particularly in cities an increased application of MBRs can be expected.
	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)

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 has increased considerably. Altogether this should facilitate the diffusion of MBR reclamation technology. However, there is no yet a clear evidence for a strong regulatory advantage for on-site water treatment and reclamation. By contrast, central and local governments playing an important role in the decision process in China still seem to favour centralised wastewater treatment solutions (CGTI

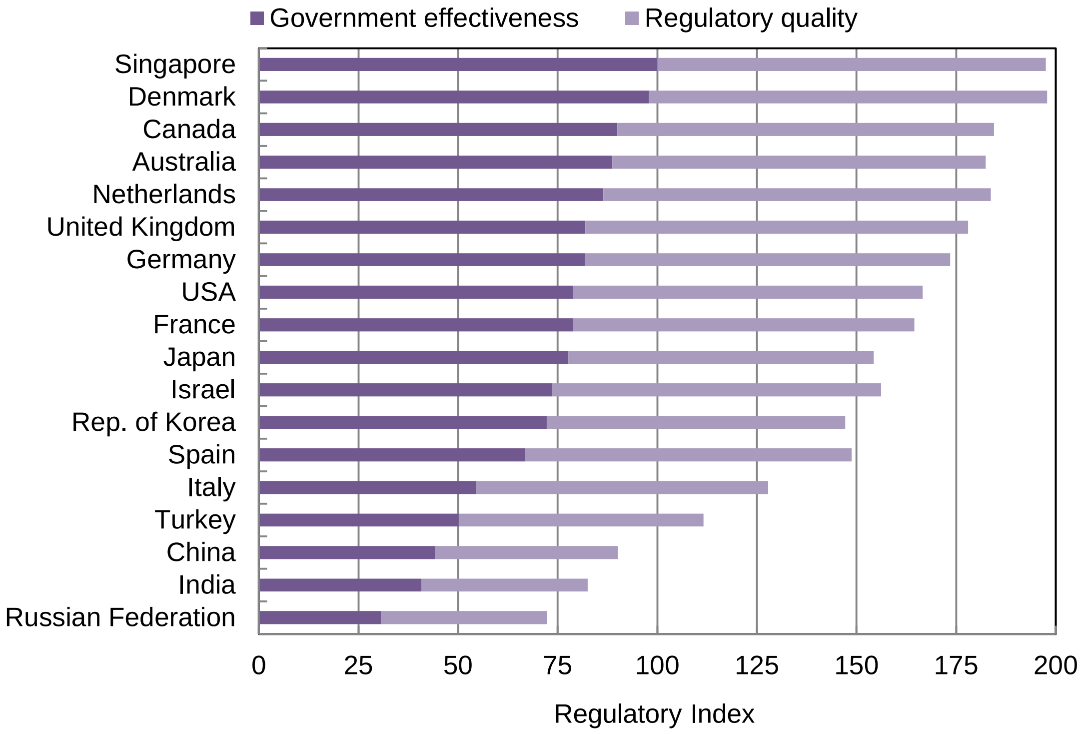
2012), an attitude evident from the large-scale MBRs deployed preferentially in the municipal but also in the industrial sector. On the other hand, particularly industrial users could prefer more decentralised solutions due to the increased costs of a pipeline network for centralised treatment and the diversified wastewater streams from different companies particularly evident in industrial parks which increase the complexity of the treatment process.

… and their implementation on the local level

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. Similar to the lack of cost-covering water tariffs (see this subsection, below) reluctant implementation on a local level is also apparent in other policy fields, such as the water standards. 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 is also documented by a recent Greenpeace investigation (China.org.cn 2012) for the more developed eastern part of China. In particular, it is shown that companies still have strong 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 wanting to sustain 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 this failure on the local level by means of such measures as the implementation of penalties like fines of up to RMB 100,000 or production halts for companies. Additionally, key performance indicators (KPI) used to evaluate and promote government officials are not based anymore on the basis of economic performance only.

The former argument is confirmed by an international comparison, where China's government effectiveness in implementing and enforcing policies only ranks at the lower end (see Figure 6). It is argued that as long as the lack of implementation persists, MBR technology is unlikely to diffuse countrywide but will remain a technology for the highly developed coastal areas.

Figure 6: Estimation of regulation enforcements for selected countries.



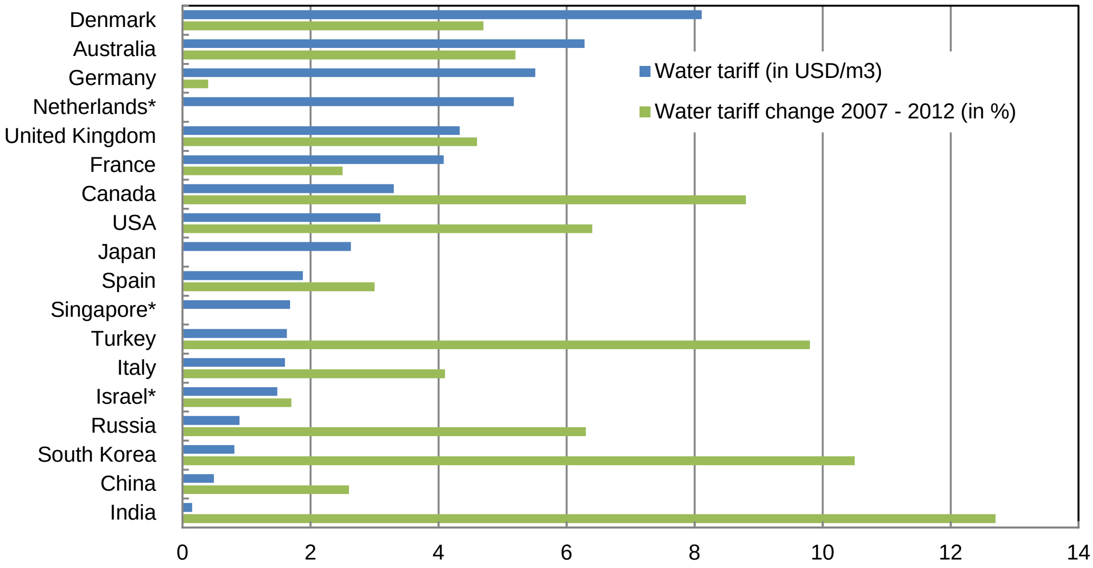
Source: GII (2012)

Although a general lack of central policy implementation can be identified, there are at least eleven cities in the north of China where the administrations increasingly enforce 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 meet this target all wastewater treatment plants have to be upgraded to wastewater reuse plants (Peng 2012).

Water price subsidization

Water tariffs represent the actual benchmark for the price consumers have to pay for water and against which alternative (private) water suppliers may have to compete. Accordingly, higher water prices would make the use of recycled water and MBR more attractive, while lower prices may impede the diffusion of this technology. While the cost of water supply may vary depending on the respective local conditions, water tariffs are far more determined by regulation – be it subsidies making water more affordable for the poor or high quality standards rendering the water supply more expensive. In addition to the average water tariffs applied in a variety of countries, Figure 7 provides figures concerning the average price increases over the last five years. In those cases where the tariffs are rather low – giving rise to the presumption that water may be subsidized – price increases may indicate that this practice will be phased out in the future, enabling alternative water supply approaches to gain a foothold more easily.

Figure 7: Average water tariffs for individual households and their change between 2007 and 2012



Notes: For the Netherlands, Singapore and Israel average household water tariffs and changes have been calculated based on the available data from the survey.

Source: GWI (2012) and own calculations

Evidently, the price of water appears to be higher in industrialized countries than in emerging economies. By contrast, average tariff increases in the recent past seem to be higher in countries with lower water prices, which indicates that these countries are striving for a higher water price level covering more completely the actual cost of water supply. With its low (residential) water price and its low increase, however, China belongs to those countries, in which private investment into innovative water supply technologies does not appear to make economic sense. Interestingly the small increase by only 2.6 percent appears to indicate a lack of enforcement of national rules on the local government level, as the National Development and Reform Commission, which is responsible for pricing policies in China, had originally intended an increase by 68 percent from USD 0.13/m^3 to USD 0.19/m^3 of water (GWI 2011). This also sheds some light on the effectiveness of the implementation (including enforcement) of environmental policies, which will have to be discussed further in the context of the regulatory advantage (in section 5.3).

MBR technology design standards

While this working paper is written, 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 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 2).

Table 2: 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".

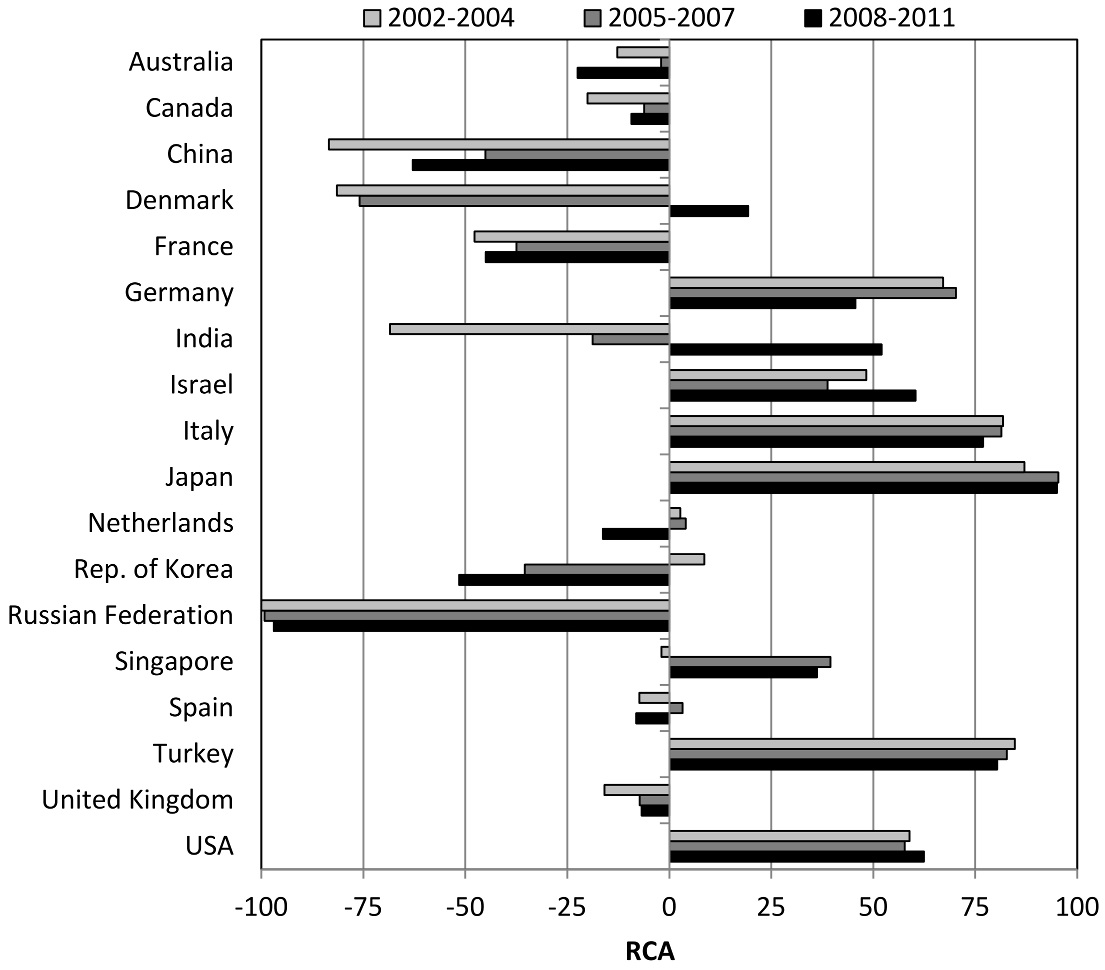
Source: (Frost & Sullivan 2011b).

Employing such comprehensive standards constitutes a clear regulatory advantage in China, as these standards will focus the respective technology demand and the associated development 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 – which leads to transfer advantage in the following section.

4.4 Transfer advantage

The transfer advantage describes the ability of a country to shape the preferences and demand of other countries for a certain technology (see section 3.4). The influence on foreign demand and preferences is dependent on the visibility of a national innovation design and therefore influenced by the export orientation of a country. Due to its strong export orientation the international visibility of Chinese products is generally high. However, as Figure 8 shows, its export specialisation on MBRs and water filtration machinery is highly negative and does not show a positive trend. By contrast, all actual market leaders – USA, Japan and Germany – show a highly significant export specialization.

Figure 8: Export specialisation (measured as RCA) on MBR and water purifying devices for selected countries.



Source: UN Comtrade (2011).

As Beise (2004) notes, the overall transfer advantage is rather difficult to approximate with quantified indicators. While the transfer effect itself can be measured by the export data as shown above, reputation and recognition of a country for a specific technology is difficult to assess. Such important events as the Olympic Games in Beijing[9], the Shanghai Expo and the Guangzhou Asia Games in 2008 and 2010 certainly helped to raise attention for large-scale MBR plants that have been installed exclusively for these events and have been a growth driver for the MBR market. It remains unclear, however, whether this rise in attention will also lead to an increase in demand for Chinese MBR from abroad. The standardization efforts mentioned in the previous section may be helpful in this respect.

Whether the erection of large-scale systems and the establishment of uniform standards are indeed able to demonstrate the maturity of the technology and indicate that the perceived risks for investments in MBR plants may declined was also assessed in expert interviews with two German MBR suppliers and one research institute. According to both suppliers, a major advantage for China arises from membrane production, which, in contrast to MBR modules, appears to have a good performance-to-price ratio (cf. China's dominance in photovoltaic cells production). One supplier further confirmed a stronger dominance and visibility of Chinese manufacturers at international exhibitions and conferences and a general trend that technological innovations are increasingly introduced in the Asian rather than the European and American markets. Overall they see the Chinese market developing towards the production of very cost-competitive MBR systems.

With regard to the transfer advantage it may be concluded that, at the moment, Chinese companies draw their advantage more from competitiveness in terms of prices than quality. Accordingly, the advantage turns out to be quite moderate. With the introduction of design standards for MBR (as shown in section 4.3) this situation may change especially if these standards were established outside China.

4.5 Export advantages

Countries whose environmental, regulatory and social conditions are similar to conditions in other countries are more likely to develop MBR systems that are accepted and can be operated elsewhere in the world. Therefore similarities between conditions at home and abroad create export advantages (Beise 2004). As indicated in Figure 9, all water-related environmental conditions in China are close to the global average, which is located at the centre of the web chart. That is, its requirements on water quality and

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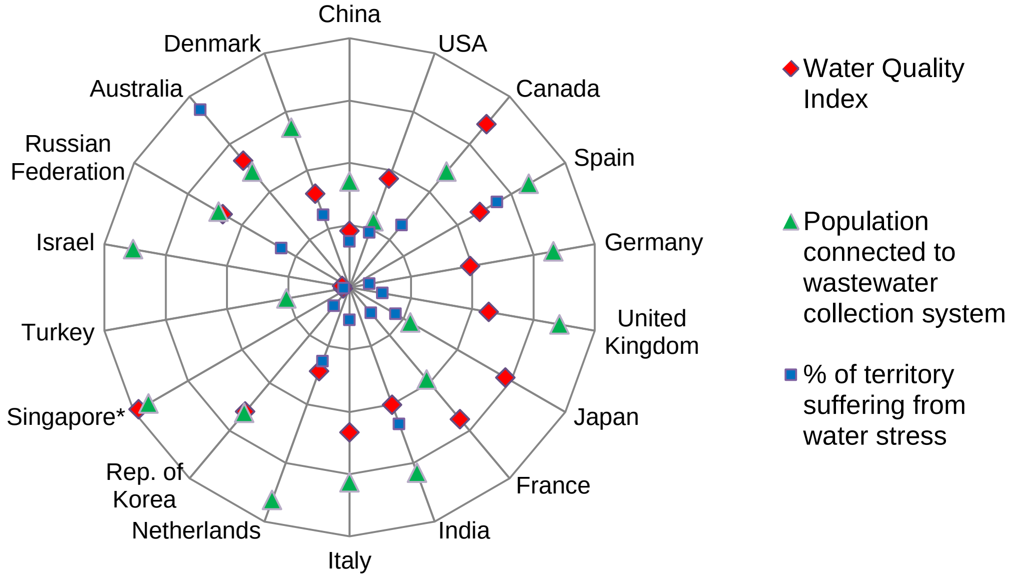
[9] For the Olympic Games an MBR plant with a wastewater treatment capacity of 60,000 m^3/d and a reuse capacity of 10,000 m^3/d was constructed by Siemens AG (2008).

water reuse facilitate the production of MBR systems that could potentially be operated in many different countries. Yet China's lower performance with respect to "Population connected to wastewater collecting system" (42 percent as compared to a global average of 62 percent) is of special interest. On the one hand a poorly built out sewer system incentivises (semi-) decentralised as opposed to centralised systems. On the other hand it requires rather large-scale than small on-site treatment, at least in the municipal sector. Albeit large-scale municipal plants constitute a large proportion of the worldwide demand (Frost & Sullivan 2008), particularly in the developed countries that are still leading the production of MBRs large-scale Chinese systems might therefore not diffuse.

Figure 9: Environmental standardisation potential for MBR technology.

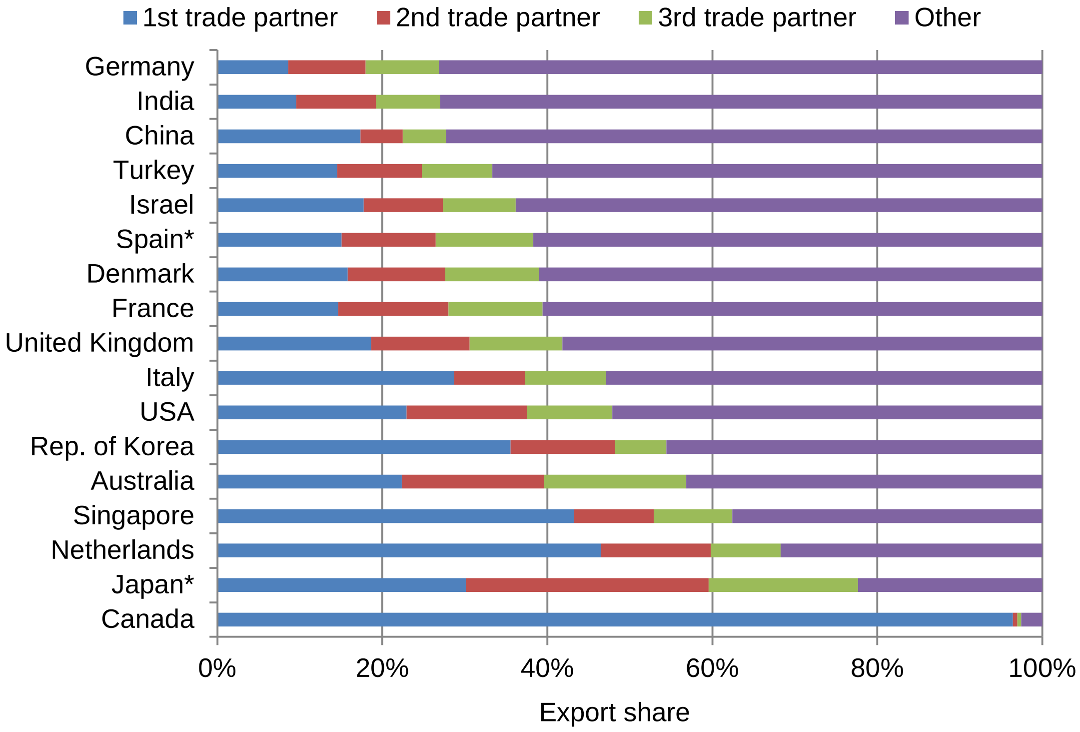


Note: The standardization potential is approximated by the proximity of national environmental conditions compared to the global average represented by the centre of the web chart. For Singapore data on water stress were not available.

Source: EPI (2010a), EPI (2010b), OECD (2012)

Another means of assessing the potential for China in the development of worldwide adoptable MBR systems is its export structure for MBR and water filtering machinery (Commodity code 842121) as described by the export share of the three major trading partners. As shown by Figure 10, China is amongst the three countries with the most diversified export structure for water filtering machinery. Thus, China is more likely to develop MBR systems that can be exported to many other countries than idiosyncratic systems that will only be operated in a limited number of countries. Hence, this diversified export structure indicates a significant export advantage for China.

Figure 10: Export diversification for MBR and water filtering products



Notes: For Spain only export data from 2010 were available. Japans largest trade partner(s) is filed under “Other Asia” and includes several territories such as Taiwan, Macao and Hong Kong. With regard to the fact that its 3rd largest trade partner is mainland China the overall export dependency from China is substantial.

Source: UN Comtrade (2011)

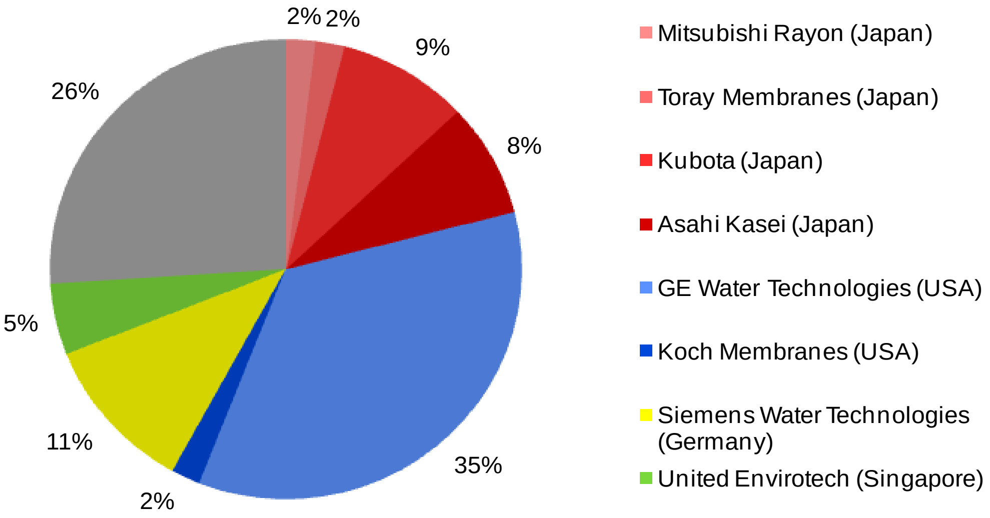
4.6 Market structure advantage

Countries with highly competitive markets are considered to be better capable of supplying more innovative designs (Beise 2004). Figure 11 reveals a highly concentrated global MBR market that is dominated by suppliers from Japan, USA, Germany and Singapore. These lead suppliers are to a large extent vertically integrated, producing membranes and membrane filtration modules and providing customers with complete MBR treatment plants typically in the form of Build-Operate-Transfer (BOT) projects. As such traditional first mover countries as the USA, Japan and Germany have a clear lead supplier advantage.

The global dominance of the lead suppliers was also reflected in the early days of the Chinese market. In 2007 Japanese Asahi Kasai and Singaporean United Envirotech accounted for more than 50 percent of the MBR market share. Four years later, however, market shares changed significantly with Beijing Origin Water Technology Company (BOW) now accounting for approximately 30 percent of the market (see Figure

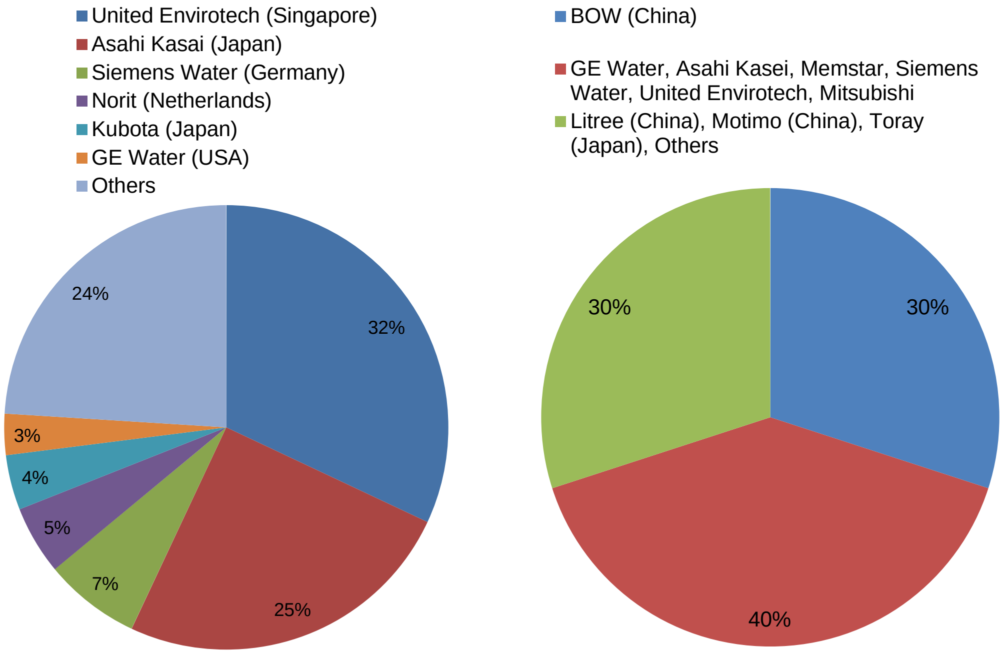
12). BOW has become the Chinese flagship MBR supplier with the largest installed capacity. Most of them were in the municipal sector, involved in representative MBR pilot projects raising international attention at locations such as the Beijing Olympic

Figure 11: Global market share of MBR suppliers in 2007.



Source: Frost & Sullivan (2008)

Figure 12: MBR market share development in China in 2007 (left) and 2011 (right).

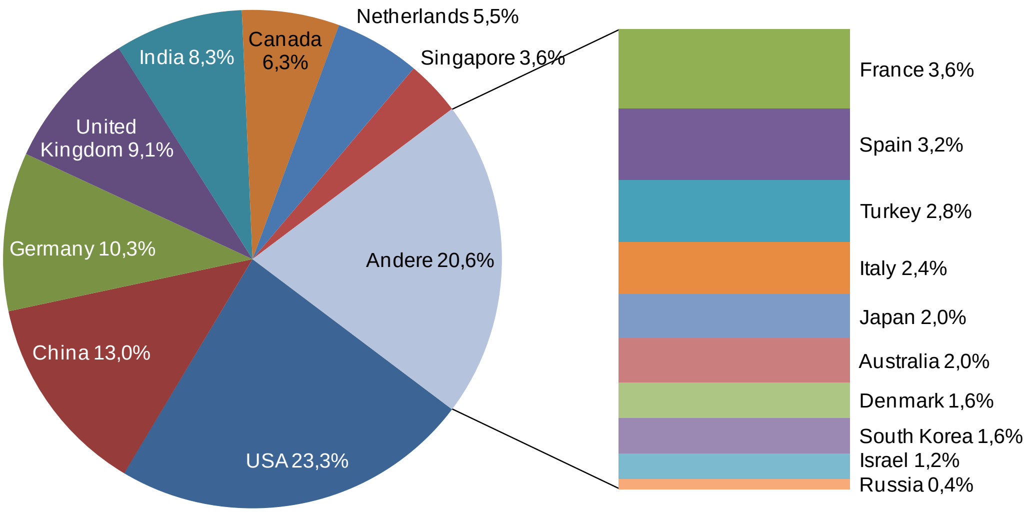


Source: (Frost & Sullivan 2008; Frost & Sullivan 2011b).

Village in 2008 or the Grand National Theatre (Peng 2012). At the beginning BOW had started as an engineering contractor using foreign MBR units, predominantly from Japanese Asahi Kasai, before providing completely integrated system solutions. Then its development to China's most renowned MBR supplier was promoted through a series of large-scale MBR plant commissions (Judd and Judd 2011).

An analysis of selected lead suppliers might not provide sufficient insights on the competitiveness of a market. Therefore the total size of the internationally visible MBR industry was assessed by the identification and analysis of online company databases. As Figure 13 reveals, the Chinese MBR industry is very vital and active featuring at least 34 of the total 251 companies that were identified for the country selection. Although there are some large HF and FS membrane producers such as Tianjin MOTIMO or Shandong Zhaojin Motian, a large proportion of the market is constituted by small and less sophisticated MBR filtration module suppliers and membrane producers. Overall the market analysis confirms the previous result that China lacks system providers that offer horizontally integrated solutions covering also the whole value chain. Although the country has a vital MBR market its expertise in providing packaged solutions is yet limited. By now BOW might in fact be the only Chinese supplier that is capable of providing complete solution packages abroad. This segment is acknowledged to drive future demand (Frost & Sullivan 2008) and even global lead suppliers such as Siemens with its XPress solution launched in 2004 deliver this segment.

Figure 13: International visibility of MBR industry (measured by the number of firms) for selected countries.



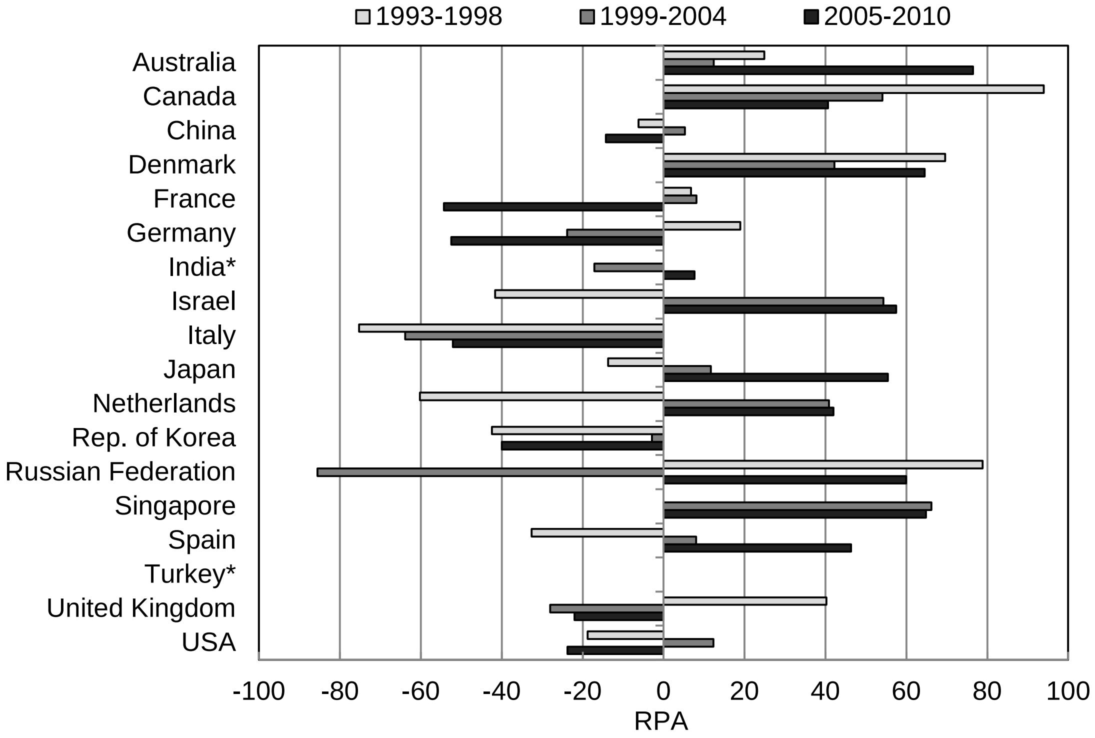
Sources: Alibaba (2012); Tradekey (2012); MBR site (2012); MBR Network (2012); Environmental Expert (2012); Water & Wastewater Direct (2012)

To summarise, the market structure for MBR in China on the one hand exhibits a large number of players on different levels of the value chain ensuring sufficient competition to force the companies to learn and realize economies of scale. On the other hand, at least one large company exists, which may serve as a system supplier and "door opener" in those countries into which MBR facilities might be exported in the future.

4.7 Supply-side advantage

Factors leading to a supply-side advantage are knowledge and expertise, which enable the actors within an industry to actively develop, produce and market innovative technologies. Knowledge and expertise on MBR was approximated by patent applications. With regards to patent applications in the field of membrane filtration between 1993 and 2010 the Revealed Patent Advantage (RPA) does not show a significant specialisation for China (cf. Figure 14). However, keeping in mind China's increasing lead in the production of photovoltaic cells production despite its low patent specialisation in this field (Walz 2011) sufficient expertise for the production of MBR systems may nonetheless be existent.

Figure 14: Patent specialization (RPA) for membranes-related innovations

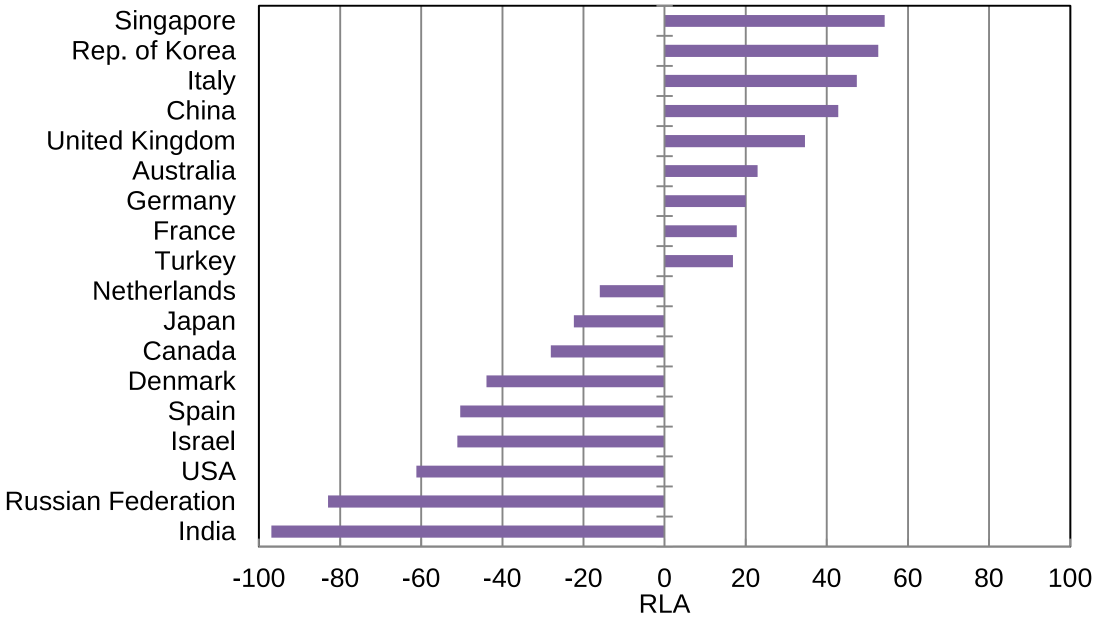


Note: For India no patent applications were available for the years 1993 – 1998, whereas for Turkey no patent applications were available for the entire period analyzed.

Source: PATSTAT (2012), own calculations by Fraunhofer ISI

Apart from the patent analysis, expertise and knowledge were further estimated by the Revealed Literature Advantage (RLA), which shows the literature specialisation of a country on MBR in comparison to all publications in four major water, membrane and desalination journals. In contrast to the RCA the RLA data summarized in Figure 15 confirm a high specialisation on MBR publications for China. From all MBR related articles published in the four considered journals between 1986 and 2012, 22 percent were published by authors with Chinese affiliation. Summing up, there is considerable evidence of existing and increasing Chinese expertise in the field of MBR technology.

Figure 15: Literature specialisation (RLA) on MBR for selected countries.



Source: ScienceDirect (2012), own calculations of Fraunhofer ISI.

Yet another important factor worth considering 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 on the supply-side for 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 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 Chinese actors are at least not directly part of these clusters and as such not represented in the membership structures.

In contrast to the global perspective 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 Section 4.3 and a considerable number of firms as well as research institutions in that field. However, these actors act rather 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.

5 Discussion of the results

Due to high water stress and poor water quality prevailing in major parts of China, there is a strong need for better wastewater treatment and water reclamation. Accordingly, the **demand advantage** for MBR plants in China should be very high – higher or even much higher than in actually leading MBR supplier countries like USA, Japan or Germany. As a consequence of this water shortage, China is exploring all kinds of water sources including, for instance, water desalination or the South-North water diversion, which are both much more expensive than ordinary water extraction. From this perspective, water reclamation by MBR may be an economically useful alternative in this context, which the government may be willing to subsidize more extensively in the future.

This, however, leads to the challenge that the existence of water shortage and bad water quality as such are insufficient to improve the conditions for the supply of a sufficient volume and higher quality of water. Strict regulation by the government is needed to ensure that existing water sources are not polluted, wasted or overexploited and new, often more costly sources are developed. With regard to MBR, such a strict regulation could yield a **regulatory advantage** as it increases the demand for this type of water reclamation technology. In this context, China's water resource and environmental policy is characterized by far-reaching objectives, which indeed account for the existing problems and are supported by substantial financial resources (as shown in Table 1). However, the implementation of these policy objectives is hampered by the decentralized, highly hierarchical character of the political administration (see Figure 7), which, especially on the lower, local level, leads to the dilution of the high-level goals and a stronger pursuit of diverging regional, local or even personal interests and a lack of monitoring and enforcement (Chen 2009). Additionally, the water price (tariff) at least for municipal water consumption in China is very low, which renders the reclamation of water by means of MBR technology economically even less competitive than in most other countries. Although (due to decreasing subsidies) water tariffs are expected to increase substantially, this will not change the competitive stance of MBR in the near future. For the MBR plants constructed and operated in China today (Zheng et al. 2010), special circumstances (e.g. high international visibility and reputation) are more decisive than economic competitiveness. The situation in China is different in the commercial sector and in industry, where water is less subsidized and, therefore, more expensive. Here, like in most industrialized countries, wastewater treatment by MBR is often economical. Altogether, China's regulatory advantage as resulting from its rather ambiguous policy goals is as yet certainly not higher than that of Japan and Germany, but could increase substantially once the implementation of the goals and the water price structure will be improved.

Although Chinese manufacturers are able to supply MBR facilities and components at lower prices than suppliers from USA, Japan and other industrialized countries, they cannot (yet) benefit fully from this **price advantage** because the quality of Chinese MBR plants and components is often (but decreasingly) considered worse than the quality supplied by the foreign (mainly Japanese) competitors. So, the price (and cost) advantage of Chinese manufacturers can have an effect, if the quality issue is settled.

While Chinese manufacturers of membrane modules and MBR facilities supply a substantial share of their home market, their exports are confined to a low level, which is in stark contrast to Chinese exports in general. By contrast, for the main supplying nations of MBR – USA, Japan and, to a lower extent, Germany – export of this technology performs even better than their good general exports. Accordingly, China shows a lower **transfer advantage**, which could however change in the future, if Chinese MBR manufacturers succeeded in realizing and maintaining their price advantage and increasing the quality of their products. The attempt to establish standards for the design and operating performance of MBR facilities appears to be a good first step in this direction. Another advantage for Chinese MBR manufacturers and their export potential results from the fact that the conditions for MBR application in China (i.e. high water stress, low water quality, poor wastewater treatment) are representative for most countries in the world. So, the products initially developed for the home market would also meet the foreign demand. The same would be true for the USA and, to a lesser degree, Japan, whereas conditions in Germany appear to be more atypical, which tends to be an indicator for a more idiosyncratic development. Like China, Germany nevertheless shows a high diversification with regard to its export partners, which indicates a strong **export advantage** in both cases. The respective indicators for the USA and Japan are weaker, although this may be due to an artefact in the latter case (see Figure 10 and its notes).

On the supply side of the MBR market two advantages are distinguished: **market structure advantage**, which tries to assess the competitiveness of the MBR industry of the respective country on the basis of numbers and sizes of the relevant companies, and **supply advantage**, which focuses more on the technological capacity and interaction of the companies, which in turn are considered as important prerequisites for their competitiveness and export performance in the future. From the data provided in section 4.6 it is evident that more than one half of the MBR market is supplied by three firms and two thirds by five firms, all coming from the USA, Japan, Germany and Singapore. However, this relatively small number does not appear to give rise to limited competitiveness, as all of those suppliers are simultaneously supplying the Chinese market. Instead, the small number of suppliers seems to be caused by the fact that MBR manufacturers are vertically integrated and a critical size has to be exceeded in order to supply their integrated products and serve foreign markets. In the more recent past, between 2007 and 2011, several Chinese suppliers additionally entered the Chinese market for MBR, with one of them (BOW) supplying 30 percent of the newly installed MBR capacity. This is another indication that the MBR market in China is indeed contestable and, as a consequence, competition is not hampered. At least this is true with regard to the incumbent firms from outside China.[10]

The technical capacity of China, as measured by its patent specialization for MBR related inventions, is about as good (with lower absolute numbers) as for the main global suppliers USA, Japan and Germany. The specialization of Singapore is better, albeit on a substantially lower absolute level. The specialization in terms of scientific publications (i.e. scientific perfomance) is even better for China than for Germany, Japan or even the USA – only the performance of Singapore is better. All this raises the impression that Chinese manufacturers are on the brink to catch up in the development of MBR. In line with this view is the finding that the large MBR manufacturers in China are supplemented by a substantial number of smaller firms situated all over the value chain. However, the sheer numbers of publications, patent applications and companies do not tell the whole story. Another decisive factor is the interconnectedness between the companies and other decisive actors from science and political administration. While such a network seems to exist on the national Chinese level (Binz 2008), the global view yields an ambiguous picture. Chinese actors are only weakly connected to the existing global networks for MBR, in which the USA, Japan, Germany and Singapore play crucial roles (Yi and Shi 2012). On the other hand, global connections seem to exist for membrane wastewater treatment technology. For the supply side altogether this means that Chinese companies are indeed becoming the most important players within China. Outside China, however, they hardly play a role as yet. Whether and how this will change in the future is difficult to estimate.

For an overview, the preceding evaluation of the lead market advantages of Chinese and other suppliers of MBR technology is summarized in Table 3.

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[10] In this context, it is unclear whether contestability will persist with regard to the Chinese companies as they possibly take unilateral advantage from subsidies or other benefits from the Chinese government.

Table 3: Summary of the lead market potential for MBR technology for selected countries

	CN	DE	IL	IT	JP	NL	SG	KR	US
Demand advantage	⊕	⊙	⊕	⊙	⊙	⊙	⊕	⊙	⊕
Price advantage	(⊕)	⊙	⊖	⊙	⊙	⊙	⊙	⊙	⊙
Regulatory advantage	⊙	⊕	⊙	⊙	⊕	⊕	⊕	⊙	⊕
Export advantage	⊕	⊙	⊕	⊙	⊙	⊙	⊖	⊙	⊙
Market-structure advantage	⊙	⊙	⊖	⊖	⊙	⊙	⊙	⊖	⊙
Transfer advantage	⊖	⊕	⊕	⊕	⊕	⊙	⊕	⊙	⊕
Supply-side advantage	⊙	⊙	⊙	⊙	⊕	⊕	⊕	⊙	⊙

Notes: ⊕, ⊙ and ⊖ indicate higher, average and lower performance, respectively.

6 Implications for lead market strategies

The analysis undertaken in sections 4 and 5 reveals that at present the USA, Japan and Singapore are the countries with the highest lead market potentials – followed by the Netherlands, Germany, China and Israel. Four of them, the USA, Japan, Germany and Singapore are in fact the biggest supplier countries of MBR plants. And each of the latter four had its specific motivation to develop and employ the MBR technology: the USA because of the high run-off water quality, Japan because of the compactness of the plants, Germany for both reasons and Singapore because water was to be reused extensively. Although a substantial number of MBR plants was successfully deployed on its respective territory and exported abroad by each of these countries, the MBR technology so far remained a niche technology for wastewater treatment, especially in the municipal sector. As Lesjean et al. (2011) argue, MBR will never displace conventional wastewater treatment technology in the foreseeable future. So, MBR will continue to occupy a niche market, albeit an increasing and, eventually, rather large one. And China will be part of this growing market on the demand side and also and increasingly on the supply side.

In order to develop and exploit a lead market on its own, China would have to meet certain requirements corresponding to its existing (or lacking) lead market advantages. As can be learnt from Table 3, China's performance regarding the demand and export advantage is already quite good, although the latter potential has not yet been realized, as China has not yet exported MBR facilities significantly. The major drawbacks for the expansion of MBR capacities on the Chinese home market are the too low (i.e. subsidized) price of water supply at least in the municipal sector and the (as yet) insufficient implementation of the quite demanding national objectives for water management on the local or regional level. If these drawbacks were eliminated and, as a consequence, the market started growing, a third barrier would have to be removed: the lower quality of Chinese MBR facilities and components thereof and, accordingly, the not so good reputation of the respective Chinese manufacturers. The latter point is of course also important for opening an increasing share of the global market to Chinese suppliers. But access to the global market is not only a consequence of better technical performance; the latter improvement is, in turn, dependent on the interaction – domestically and abroad – with actors involved in the development and manufacturing of MBR plants and their components. In the view of Binz et al. (2012), these interactions form the basis of a technological innovation system (TIS), which includes all actors relevant for pushing the development and production of MBR and its components. The TIS is especially decisive for an emerging country like China, which has to progress as efficiently as possible in environmental and economic terms and, therefore, should not and cannot afford repeating anew the development of MBR technology already undertaken in other countries. If China's TIS for MBR succeeded in increasing its performance with regard to the above-mentioned less well-performing lead market factors, the sheer size of its home market and the resulting opportunities for learning and scale effects could provide it with the extra push needed to outcompete at least partially the main competitors form the USA, Japan and so on. In this case, China could indeed be the basis for a lead market – adopting a second-mover strategy for its exploitation, because China was not among the first countries developing and employing the MBR technology.

Following this potential lead market scenario for the MBR technology in China, how could the leading actual MBR suppliers from such countries as the USA, Japan or Germany react on it? As the Chinese government will prefer domestic companies supplying the Chinese market for MBR and support them accordingly, it will be difficult for any foreign supplier to increase its market share in China significantly in the longer run. In order to learn and further develop the technology on their own part, the actual market leaders will have to expand their market (shares) elsewhere. This means that they have to intensify their scientific and research activities, in order to improve the MBR technologically or in terms of price and independently of the large Chinese market. Additionally, the actually leading suppliers of MBR technology could, and would have to, improve their own market potential by increasing their export advantage, i.e. by better adapting their technology to the needs and cultural specificities of potential importing countries. The water infrastructure typically produced and employed in Germany, for instance, is mainly centralized and of high technical standard and very good performance with regard to the quality of supplied fresh water and treated wastewater. It fits well in newly established urban settlements, but is less suitable for either long established, rapidly growing cities (which are not easily upgraded) or remote, rural areas. The latter two cases are also those addressed by the Human Development Goals, according to which the number of people lacking proper fresh water supply and sanitation is to be halved by 2015. In Germany, we have got technical solutions addressing also these problems (e.g. decentralized wastewater treatment), but they are often too expensive, require too much knowledge and/or are not sufficiently robust for being used in developing countries. Developing and producing such equipment in Germany is, however, a challenge as there are no domestic customers to test and improve this type of technology.

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