Water-reuse concepts for industrial parks in water-stressed regions in South East Asia


ABSTRACT

With regard to the water shortage in several regions of South East Asia, the paper focuses on the development of a sustainable Industrial WasteWater Management Concept with the focus on Reuse (brand name: IW²MC → R) to reduce water consumption from natural resources. The IW²MC → R includes the sustainable treatment of wastewater in industrial parks (IP) to provide reuse water for different purposes. The main objective is to reach the highest possible Industrial Park Reuse Factor (IPRF). The IPRF describes the relation between wastewater inflow to the central wastewater treatment plant and the outflow of reuse water for different applications. The Infrastructure Reuse Factor (IRF), one component of the IPRF, relates to infrastructural reuse applications (e.g. irrigation, street cleaning, toilet flushing). To determine the IRF, a model industrial park is applied. A first calculation resulting in an IRF of ~25% includes reuse applications for irrigating green spaces, street cleaning, and toilet flushing. In cases when other applications for reuse water are considered (e.g. cooling or firefighting water), the IRF can be higher than 25%. Thus, the IW²MC → R provides a sustainable solution strategy, especially for water-stressed regions, to drive new IP developments by reducing water extraction from natural resources.

Key words | fit for purpose, reuse factor, reuse water, sustainable wastewater treatment, water-reuse concept for industrial parks, water-stressed regions

INTRODUCTION

With its megacities and urban areas, South East Asia belongs to the world’s fastest-growing regions with high urbanization rates. Urbanization has a large influence on the expansion of existing IPs and respectively the development of new IPs. Vice versa, IP developments – especially in China – are a significant factor for urban developments (Zhao et al. 2017). Several investigations have shown the extent of spillover effects to the local environment (Zheng et al. 2017). Worldwide, industrial Production Plants (PP) are increasingly placed in planned IPs to ensure regional compatibility and the plants’ special supply and disposal demands. Due to water shortage, e.g. in China and Vietnam, and increasing environmental awareness, sustainable water supply is becoming more and more important. IPs, especially, have high water requirements depending on their individual PP and processes, and also need water for infrastructural purposes, such as street cleaning or irrigation of green spaces. Especially in water-stressed regions, industrial water demand increasingly competes with municipal and agricultural water demand, often resulting in the limitation of industrial expansions. Therefore, the development of new sustainable water-reuse concepts for IPs to reduce
their high water consumption from natural resources is an important approach to enable more flexible and sustainable IP developments, especially in regions with high water-stress indices (e.g. western parts of China and northern parts of Vietnam).

This paper presents the development of an innovative, sustainable Industrial WasteWater Management Concept with the focus on Reuse (IW²MC→R). The concept includes the sustainable treatment of wastewater in IPs to provide reuse water for different infrastructure purposes such as water for irrigation, street cleaning, and toilet flushing. To accomplish the goals of a sustainable IW²MC→R, the following parameters and requirements have to be considered respectively achieved:

- The **Industrial Park Reuse Factor** (IPRF), describing the relation between wastewater inflows (IF) to the Central Wastewater Treatment Plant (CWWTP) and the reuse water outflows for various reuse applications, should be as high as possible. An additional **Infrastructure Reuse Factor** (IRF), as one component of the IPRF, relates to the infrastructure reuse applications (irrigation, street cleaning and toilet flushing), which can be calculated separately.
- The reuse water undergoes an optimized wastewater treatment process (for example, activated sludge process (ASP)) according to the principle ‘fit for purpose’ depending on the intended application.
- The **energy consumption** of the CWWTP and the additional Water Reuse Plant (WRP) has to be less or equal to that of the Central Water Treatment Plant (CWTP). The energy required for the conveyance and treatment of raw water and the subsequent distribution typically is in the range 0.35–2.8 kWh/m³, depending on the water source and specific regional parameters. In cases in which desalination is applied, the energy demand increases to more than 5 kWh/m³ (Lazarova et al. 2012). Low consumption values are achieved by applying optimized aeration technologies, which account for up to 70% of the total energy requirement of an activated sludge process (ASP; Jenkins & Wanner 2014). Furthermore, nitrification/denitrification is not required when treating water for irrigation, thus reducing the energy consumption up to 40% (Wagner 1992).
- Via **area-saving construction**, thus reducing the consumption of land, the WRP is assumed to take up no more than an additional 10% of the area of the CWWTP. For example, the oxygen transfer can be reduced by installing particularly deep reactors/tanks, using the reactor design to reduce area requirement. This is particularly important due to the restricted availability of space for treatment plants (Ranade & Bhandari 2014). Available space is preferably used for the construction of PP, indicating the necessity of optimizing the different treatment processes in order to reduce land consumption by CWWTP and WRP and thus ensure the sustainability of the IW²MC→R. Applying membrane processes is another measure to reduce land consumption. Due to the low inflow loads from the CWWTP to the WRP, the dimension of the latter is assumed to take up no more than an additional 10% of the area of the CWWTP.
- The treatment processes are to be optimized in order to reduce the consumption of resources (for example, biological phosphorus removal instead of precipitation (reduction of operating materials) or use of fine bubble aeration systems instead of surface aeration systems (reduction of energy)).
- High automation level of the treatment processes is to be achieved in order to secure a high quality level of the produced reuse water. For example, using online measurement and smart glasses for maintenance could be an opportunity. A high automation level in connection with disinfection of the treated wastewater ensures a high quality level of the produced reuse water.

**METHODS FOR DEVELOPING A SUSTAINABLE WATER-REUSE CONCEPT**

In order to identify water-reuse applications and thus enable the development of the sustainable IW²MC→R concept, several investigations in South East Asia were carried out to get an overview on the existing IP systems. Therefore, besides the analysis of statistical and available online data of industrial parks as well as an aerial photographic exploration, an in-depth case study investigation was conducted. This investigation included interviews with technical and
management experts from water supply and wastewater treatment plants and on-site visits to IPs in China and Vietnam. Furthermore, interviews with German IP experts were conducted. For better comparability of the results from the different countries, a standardized interview guideline was used, asking about three main categories: the water supply situation, the wastewater treatment technologies and the water-reuse potential. In total, data for 12 industrial parks in China and 23 in Vietnam could be compared with 39 German industrial parks. The results served as a basis for the development and adaptation of a new integrated water-reuse concept.

The focus of the investigations was on China as it was chosen as the case study for subsequent analyses and calculations (see the next section). A first result of the investigations is that in China, parks with diverse industries are much more common than thematic parks. In addition, China is particularly dynamic in developing greenfield areas as new IP locations. Furthermore, due to the uneven distribution of natural water resources and the partly high levels of pollution of waterbodies, water shortage is a challenge in South East Asian countries (World Resources Institute 2018). In addition, China is, besides the United States, the country with the worldwide highest water usage for industrial purposes (FAO 2017). This is, inter alia, related to the large sizes of IPs in China with an average of 1,188 ha (concerning eight cities: Beijing, Shanghai, Shenzhen, Dialian, Tianjin, Xi’an, Chengdu, and Wuhan) (Zheng et al. 2017). In comparison, the average size of IPs in Vietnam is approximately 300 ha (own investigation of 24 parks and Ministry of Planning & Investment (2017)).

Based on the investigations in China, Vietnam, and Germany, two typical IP systems regarding wastewater treatment (see Figure 1) can be deduced. In both systems, the CWTP uses groundwater, surface water, or tap water as raw water source and usually provides three different water qualities: drinking, industrial, and deionized water. Wastewater from the different PP is treated in a park-internal CWWTP, which, subsequently, discharges the treated water, e.g. into the receiving water body. In case of highly polluted wastewater, PP have their own on-site pretreatment. A decisive difference between the park systems is that the PP discharge their wastewater either into one collective sewer (see IP system 1) or into separate sewers (see IP system 2) for conveyance to the CWWTP. System 2 enables a more precise control of the quality of wastewater inflows from each production plant to the CWWTP. Another advantage of separate sewer systems is the higher operational stability of the CWWTP in case of an accident in one of the PP. Highly polluted or toxic wastewater can be separated immediately, thus avoiding, for example, production stoppage at other PP. However, at present, System 2 is rare in IPs. Obviously, the application of cross-company reuse water is currently also not common.

Figure 1 | Typical industrial park systems (Source: own figure – not to scale).
RESULTS AND DISCUSSION: THE IW²MC → R AS A STRATEGY FOR WATER-STRESSED REGIONS

The development of the IW²MC → R is based on the results of the investigations (see previous section) and includes two different water-reuse approaches. The case study of China is particularly suitable due to the differences in the water-stress level investigated during the country comparison of China, Vietnam, and Germany (see previous section). Thus, Chinese data, e.g. guidelines and governmental regulations, serve as a basis for the following results.

The Industrial Park Reuse Factor

The development of the innovative sustainable IW²MC → R is based on the two existing IP systems described above. The concept includes the sustainable treatment of wastewater in a CWWTP as well as the supply of reuse water for different purposes via a Water-Reuse Plant (WRP) (see Figure 2). The IW²MC → R aims at the highest possible IPRF (see Introduction). Therefore, on the one hand, the IPRF includes the IRF, which relates to the infrastructural reuse applications, e.g. water for irrigation, street cleaning, and toilet flushing (see calculation in subsection ‘Calculation of the IRF’ below). On the other hand, the IPRF includes the Production Plant Reuse Factor (PPRF), whereby it is possible to calculate the water-reuse applications for the PP, e.g. for process water (Bauer et al. 2019).

The two water-reuse approaches of the IW²MC → R

Referring to the typical IP systems, the IW²MC → R can be specified into two different (theoretical) water-reuse approaches. Both approaches are based on the current wastewater treatment systems in an IP including the existing layout of pipes and sewers.

Water-reuse approach 1 (see Figure 3) is linked to the first typical IP system, where wastewater is discharged to the CWWTP in one joint sewer system. Regarding the CWWTP, this system only allows a few options for optimization. In this case, no further treatment adapted specifically to the respective wastewater quality is possible than that which would be possible with separate sewer systems. Hence, due to the combined collection of wastewater from different productions in one sewer system, treatment systems have to be diverse and flexible. This enables the handling of changing wastewater volume flows respective to qualities, as well as meeting the required discharge qualities. In such a case, common treatment concepts for industrial wastewater mostly provide for a four-step process chain. Step 1 includes the so-called head works, i.e. mechanical treatment processes, such as grates, sieves, and sand trap. Step 2 consists of mixing and expansion tanks with the potential connection of a neutralization unit if needed. Precipitation and flocculation are carried out in Step 3. The biological wastewater treatment unit, Step 4, is the key component of the treatment chain. Worldwide, the ASP still is the preferred process due to its robustness and adaptability. Caused by the mostly successive development of IPs, the number of treatment tracks often is identical to the number of development phases of the overall IP. Due to the joint sewer system of all productions and the resulting mixing of wastewater flows, treatment tracks normally are of identical design. Splitting the treatment steps, particularly the biological unit, into several tracks offers the advantage of increased flexibility and robustness in case of malfunction.

Water-reuse approach 2 of the IW²MC → R, based on the typical IP system 2 (see Figure 3), discharges the wastewater from the several PP within parallel sewers to the CWWTP. Compared with system 1, this design already enables an optimized operational management of the CWWTP. Optimization potentials start with the specific...
selection and mixing of wastewater partial flows. For example, alkaline and acidic partial flows could be neutralized when mixed. According to the IW²MC → R, the further classification of the wastewater flows depends on their biological treatability. Wastewater only loaded with organic compounds is treated in a biological treatment unit that is designed for carbon elimination only. Wastewater heavily polluted with nitrate, e.g. from fertilizer production, is treated in a treatment unit with denitrification only. In this case, wastewater partial flows heavily loaded with organic compounds can be used, if need be, as organic carbon source, dosed via a bypass. The same applies to wastewater partial flows loaded with ammonium or phosphorus. This way, the biological treatment unit as key process component of all treatment tracks and the step with the highest energy demand and costs, at the same time, could be optimized via a specific design concept. In cases when wastewater partial flows cannot be treated biologically, they are treated in a separate treatment track. Such is the case for wastewater with (very) high salt concentrations or high concentrations of non- or poorly degradable compounds. They could be treated in a desalination unit (e.g. via reverse osmosis (RO)) or be incinerated, provided amounts and required efforts are in a reasonable relation. Further wastewater partial flows are to be treated in the respective treatment tracks according to their constituents. Thereby, compliance with the required discharge qualities is the top priority.

In addition, the IW²MC → R concept provides for the pre-treatment of wastewater partial flows in the case of high pollution load, before being allowed into the CWWTP. For example, wastewater from paint and lacquer production is often highly loaded with heavy metals and/or non- or poorly degradable COD, and mostly contains high concentrations of inorganic solids. In such cases, heavy metals are removed by precipitation. Poorly degradable COD is pre-treated via oxidation processes (AOP process) before entering the biological treatment unit. Inorganic solids are usually removed via filters.

In both systems, the discharge from the CWWTP is further treated within separate units in the WRP. The treatment tracks differ in their composition depending on the different discharge qualities to be achieved, which in turn depend on the intended use of the water treated in the WRP and associated requirements, such as technical codes or legal guidelines (see subsection below.

Figure 3 | Two different water-reuse approaches of the sustainable IW²MC → R (Source: own figure – not to scale).
on ‘Requirements for reuse applications in industrial parks’). Water for irrigation purposes, for example, could be treated via an anaerobic membrane bioreactor (AnMBR). Organic matter and solids are retained, while nitrogen and phosphorus, as essential nutrients for plants, are preserved. In this case, it is also conceivable to charge the AnMBR with the inflow of the CWWTP biological unit via a direct bypass. This way, the conventional aerobic treatment within the CWWTP is evaded, thus further reducing energy consumption and costs for nutrient elimination, which is unwanted here. In cases when water is treated to be used for toilet flushing or street cleaning, thus requiring nutrient elimination, a conventional membrane bioreactor (MBR) might be applied. This process offers the advantage of the total retention of all solids and a (limited) disinfection effect while showing high process robustness, at the same time. In addition, this process module shows little land usage, caused by high potential biomass concentration and accompanying high volume turnover.

When looking at the requirements for the different water usages, one can identify different process technologies often to be used in the WRP, as well. Fine screens and sieves are crucial within the so-called head works. This mechanical equipment is necessary in order to protect the downstream process units against clogging/damage (especially MBRs). In addition, due to the mostly discontinuous loading of wastewater and the withdrawal of treated water for respective applications, storage and expansion tanks are required at the inflow and outflow of each treatment track. As the application of the treated wastewater demands high standards regarding hygiene parameters, a disinfection unit is needed at the end of each treatment track within the WRP.

Figure 3 gives a conceptual overview of the two described water-reuse approaches (it should be remarked that the illustration is not to scale). Due to the low inflow loads from the CWWTP to the WRP, the dimension of the latter is assumed not to be more than an additional 10% of the area of the CWWTP. With the opportunity of taking reuse water instead of treated raw water (e.g. drinking water) the needed size/capacity of the CWTP can also be reduced, at least those treatment steps where dimensions are directly related to the water flow.

Requirements for reuse applications in industrial parks

For the developed IW²MC → R, the principle ‘fit for purpose’ plays an important role, i.e. reuse water should be provided at different qualities referring to the subsequent use. As the reuse-water quality is a question of governmental regulation, this subsection will give a short overview of prescribed Chinese quality standards.

Generally, the central government of China has great ambitions to encourage water-reuse solutions throughout the country. This is why there are already many policies, regulations, and standards on water-reuse to enhance further developments in this field (Rodrigues & Liu 2014; Lyu et al. 2016).

As the IW²MC → R focuses on IPs and their internal infrastructures, two standards are particularly relevant. The ‘Water quality standard for urban miscellaneous water consumption’ (GB/T 18920-2002, MoHURD 2005) contains quality requirements for the purpose of toilet flushing, street cleaning, firefighting, irrigation, vehicle washing, and construction (for extracts see Table 1). The standard addressing industrial usage, in particular, is the ‘Water quality standard for industrial water consumption’ (GB/T 19923-2005, MoHURD 2006). In this standard, requirements relating to reuse-water qualities for cooling water, washing water,
boiler feed water, and process/product water are prescribed. For calculating the IRF in this study (see subsections ‘The Industrial Park Reuse Factor’ above and ‘Calculation of the IRF’ below), three reuse purposes were taken into account. Their quality parameters are listed in Table 1 and are the basis for the selection of the treatment processes in the WRP (see subsection ‘The two water-reuse approaches of the IW₂MC→R’ above).

**Calculation of the IRF**

In order to initiate the described concept in IPs, the main task is to identify quantities and qualities of existing water flows (wastewater register and water demands) as well as suitable treatment technologies for linking these flows (see subsection ‘The two water-reuse approaches of the IW₂MC→R’ above). The use of an exemplary Model Industrial Park (MIP) offers, in contrast to the calculation of wastewater and water-reuse flows from real IPs, the possibility of modifying production types and allows the use of supplementary expansion areas to analyse the framework conditions that lead to the highest possible IPRF (see subsection ‘The Industrial Park Reuse Factor’ above).

The paper, as a first step, focuses on the calculation of the IRF, which is part of the IPRF, to estimate the potential of different infrastructural water-reuse applications. An MIP, including six different exemplary PP, serves as a basis for this calculation. As chemical, food, and beverage industries are among the industries with the worldwide highest water consumption rates, six production types from these sectors were chosen (see Table 2) to determine the MIP’s total wastewater quantity. Thus, the first calculation refers to an IP with different industries. On the basis of the European Best Available Techniques Reference Documents (EIPPCB n.d.) and other literature references (e.g. Rosenwinkel et al. 2015), data were collected for the selected production processes with regard to their wastewater flows. The unit of the given data usually was m³/ton of product or kg/ton of product (see Table 2). Thus, to get the wastewater flows in m³/d, production capacities of the exemplary PP had to be determined. Therefore, real production facilities in China were investigated to provide these data. As sanitary wastewater is discharged into the CWWTP, as well, it is calculated by 50 L/employee × day according to the Chinese standard GB 50015-2003 (MoHURD 2009).

For the dimensioning of the MIP, average values for different parameters were taken into account from 12 investigated IPs in China. As the example plants in the MIP are mainly from the chemical sector, the parks were chosen

### Table 2 | Calculation of wastewater and water-reuse flows in the MIP, example of China (Source: own figures)

<table>
<thead>
<tr>
<th>Wastewater values</th>
<th>Production capacity due to example plants in China or data referring to the MIP</th>
<th>Calculated wastewater flows in m³/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O₂ production</td>
<td>1.5 m³/t product</td>
<td>945</td>
</tr>
<tr>
<td>Polystyrene production (GPPS)</td>
<td>1.1 m³/t product</td>
<td>904</td>
</tr>
<tr>
<td>Chlorine production</td>
<td>0.62 m³/t product</td>
<td>365</td>
</tr>
<tr>
<td>Superphosphate production</td>
<td>1.25 m³/t product</td>
<td>2,914</td>
</tr>
<tr>
<td>Production of soft drinks</td>
<td>1.56 m³/1,000 L product</td>
<td>2,564</td>
</tr>
<tr>
<td>Butchery (cattle)</td>
<td>0.95 m³/cattle</td>
<td>260</td>
</tr>
<tr>
<td>Sanitary wastewater</td>
<td>50 L/employee × day</td>
<td>559</td>
</tr>
<tr>
<td><strong>Sum wastewater flows</strong></td>
<td></td>
<td><strong>8,511</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water demand values</th>
<th>Data referring to the MIP</th>
<th>Calculated reuse-water demand in m³/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilet flushing</td>
<td>40 L/employee × day (=0.8 × 50 L)</td>
<td>11,180 employees in the MIP</td>
</tr>
<tr>
<td>Street cleaning</td>
<td>2.5 L/m² × day</td>
<td>23 ha (=0.09 × 260 ha)</td>
</tr>
<tr>
<td>Irrigation of green spaces</td>
<td>2.0 L/m² × day</td>
<td>52 ha (=0.2 × 260 ha)</td>
</tr>
<tr>
<td><strong>Sum reuse-water flows</strong></td>
<td></td>
<td><strong>2,072</strong></td>
</tr>
</tbody>
</table>
according to the presence of chemical industry. Data on IP size, number of companies, number of employees and the percentage of road and green spaces were analysed for each park. To determine the park size of the MIP with six PP, the average site size per company (in ha) was calculated by dividing the park size of the investigated parks through the number of companies, assuming that the park areas are fully occupied by PP (no free construction areas) and the area is evenly distributed. The achieved data should therefore be regarded as a first approximation to be verified via real production plant sizes with their respective capacities. The calculated average size was multiplied by the number of the six PP for the MIP, resulting in a park size area of 260 ha.

The number of employees in the different parks divided by the respective park size was the second essential average value (employees/ha) to be gathered from the investigated parks. The number of employees in the MIP was calculated by multiplication with the MIP park size. This value is needed for the calculation of the sanitary wastewater flow and the water demand for toilet flushing. The water demand for irrigation depends on the area of green spaces within the MIP in correlation with the specific water demand value. According to a governmental regulation, green spaces have to take up at least 20% of the park area (MoHURD 1994). The Chinese standard GB 50282-2016 (MoHURD 2017) (for averages see Table 2) states the typical water demand range for irrigation. Based on the mentioned governmental regulation, it is possible for municipalities to specify these regulations. For example, the municipality of Shanghai determines 20% of green spaces as a minimum for IPs. In this case, newly built plants produce toxic and harmful gases, and the area of green spaces must not be below 30% of the total area of the IP (RSMGW 2007).

Other municipalities have even more restrictive regulations. For example, the municipality of Changchun in general sets a minimum of 25% of green spaces for IPs and in cases when there is production of toxic and harmful gases, the percentage rises to 40% (RCMGW 2014).

For calculating the water demand for irrigation, the average value of the indicated range given in GB 50282-2016, i.e. 2.0 L/m² × day, was taken into account. To determine the water demand for road cleaning, the overall area of roads and the required water demand per m² is relevant. Aerial photographs were analysed, resulting in an overall road space of ~9% of the park area. The findings were verified by interviews with management staff of IPs. Regarding the water demand, the average value of the indicated range of GB 50282-2016 was taken into account as the basis for the calculation, i.e. 2.5 L/m² × day. To determine the water demand for toilet flushing, 80% of the estimated overall sanitary water (50 L/employee × day) is assumed to be toilet flushing water, whereas 20% is assumed to be used for washing hands, tea kitchens, and occasional showers. Based on these analyses, the reuse-water demand for irrigation of green spaces, street cleaning, and toilet flushing within the MIP were calculated (see Table 2). Including the described indicators, calculations, and assumptions for the exemplary MIP with six PP in China, the result is an IRF of ~25% (wastewater flows: 8,511 m³/d; reuse-water demand: 2,072 m³/d; see Table 3), considering the reuse-water flows for irrigation of green spaces, street cleaning, and toilet flushing. This means 25% of the wastewater can be used to generate reuse water, thus reducing the raw water demand considerably.

According to the considered treated raw water flows, an IRF of 25% results in a water-saving potential of ~18% (treated raw water flow: 11,279 m³/d; reuse-water demand: 2,072 m³/d). In addition, the energy requirement of the CWTP can be reduced, as well (see Table 3).

The findings described above illustrate the high potential of the IW²MC → R for China. By including only three water-reuse options, there is already a high water-saving potential. In the case that further water-reuse options are taken into account (e.g. cooling or firefighting water), the IRF could be even higher. In China, especially in regions, where rainfall is very rare, the average water demand for irrigation and street cleaning is higher than the used average value, thus increasing the IRF. In regions with a lower water-stress level, differences between dry and rainy seasons have to be considered.

The calculation of the energy demand (see Table 3) makes clear that by relieving the CWTP via a high IRF, the overall energy demand is reduced, despite a higher specific energy demand for CWWTP and WRP (1.7 kWh/m³) than for the CWTP (1.6 kWh/m³). When considering the specific energy demand for the treatment and distribution of reuse water in the WRP (1.1 kWh/m³), it becomes apparent that wastewater presents an attractive raw water source, which, in this case, is even more energy-efficient than the production of water in the CWTP from
sources outside the park. This means that with increasing IRP, the relative energy saving (currently ∼4%) increases further. These findings are in line with the general experience that wastewater often presents a cost- and energy-efficient source for raw water, this especially in cases of natural raw water sources of poor quality or in cases of long transport routes (Lazarova et al. 2012). In general, it has to be mentioned, that energy consumption is less important in the case of extremely high water stress.

**CONCLUSION**

The IW²MC → R, in general, represents a sustainable solution strategy for IPs by providing reuse water for different purposes. Considering the three water-reuse applications (irrigation of green spaces, street cleaning, toilet flushing), the calculated value of the IRF is ∼25%, which is fairly high, especially in water-stressed areas. As a result, the water-saving potential is ∼18%. Considering the expansion of water-reuse applications towards cooling and firefighting water, IRF and water-saving potential will be even higher, further increasing the benefits of realizing or implementing the concept. A calculation of the energy consumption shows that energy can be saved by using reuse water. Savings even increase with increasing IRF.

Evaluating the two different water-reuse approaches and the consequently different designs of the treatment processes, advantages and disadvantages became apparent. The potential of optimization, seen from the perspective of IP operators and planners, regarding treatment processes, both in the CWTP and in the WRP, increases enormously if the individual wastewater partial flows of the PP are collected and conveyed in separate sewer pipes, compared with the approach with one sewer system, where all wastewater partial flows are mixed. In the first case, treatment tracks can be constructed to fit precisely, thus reducing energy and land requirements as well as the use of resources to a minimum.

Currently, systems with only one sewer to the CWTP are the most common in IPs, which is why in this case the implementation of the first approach is probably more expedient for avoiding higher investment costs. Both solutions provide reuse water according to the principle ‘fit for purpose’. Further analyses will be carried out to determine which of the two water-reuse approaches of the IW²MC → R is the most suitable for existing or new parks. In addition, the MIP can be used to investigate whether IPs with diverse industries and thus diverse wastewater flows and water

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**Table 3** | Exemplary calculation of the energy demand (Source: own figures)

<table>
<thead>
<tr>
<th>Water flows</th>
<th>Units</th>
<th>Without reuse</th>
<th>With reuse (IRF ∼25%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated raw water flow (drinking and deionized water)</td>
<td>m³/d</td>
<td>11,279</td>
<td>9,207</td>
</tr>
<tr>
<td>Wastewater flow</td>
<td>m³/d</td>
<td>8,511</td>
<td>8,511</td>
</tr>
<tr>
<td>Reuse-water flow</td>
<td>m³/d</td>
<td>–</td>
<td>2,072</td>
</tr>
</tbody>
</table>

**Energy requirement**

<table>
<thead>
<tr>
<th>Spec. values (kWh/m³)</th>
<th>Total requirement (kWh/d)</th>
<th>Total requirement (kWh/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWTP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw water conveyance</td>
<td>0.5</td>
<td>5,640</td>
</tr>
<tr>
<td>Raw water treatment</td>
<td>1</td>
<td>11,279</td>
</tr>
<tr>
<td>Treated raw water distribution</td>
<td>0.1</td>
<td>1,128</td>
</tr>
<tr>
<td>CWWTP and WRP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wastewater treatment CWTP</td>
<td>0.6</td>
<td>5,107</td>
</tr>
<tr>
<td>Reuse-water treatment WRP</td>
<td>1</td>
<td>–</td>
</tr>
<tr>
<td>Reuse-water distribution</td>
<td>0.1</td>
<td>–</td>
</tr>
<tr>
<td><strong>Total energy requirement</strong></td>
<td><strong>23,153</strong></td>
<td><strong>22,117</strong></td>
</tr>
</tbody>
</table>

*a*Without industrial water, e.g. for cooling.

*b*Assumption according to Lazarova et al. (2012).
demands or thematic parks with similar industries offer better framework conditions for the two reuse approaches. Hence, due to the different water-reuse approaches, the IW²MC → R provides an adaptable, sustainable solution strategy. Clear benchmarks for area and energy consumption have been defined for this purpose. Therefore, especially in fast-growing and water-stressed regions, the application potential of this concept is very high to enable the construction of new and the expansion of existing IP locations. For the successful implementation of these concepts in respective countries, a supportive government is essential as well as clear regulations for water reuse, e.g. regarding water quality requirements for different purposes. China therefore offers particularly suitable framework conditions.

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