Chapter 7
Risk and Water Management Under Climate Change: Towards the Nexus City

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Key messages

To address climate change-related risk more effectively, urgent action is needed by cities to curb their consumption of natural resources, particularly water. Operationalizing the Water–Energy–Food Nexus is a possible solution for both developed and developing economies, but requires a paradigm shift, with strong policy support by national and local governments, as well as in-depth study and testing through pilot projects.

Introduction

A growth-dependent free market economy assumes a limitless supply of natural resources. This has caused over-consumption of resources like water, energy and food. Scientists have been warning of the consequences for about half a century (Meadows 1972). Cities in particular consume far more than the carrying capacity of their hinterlands (Rees 1992). This pattern of over-consumption of natural resources has caused dangerous alterations in climate (IPCC 2014). Despite the apparent risks associated with climate change, demand for these resources continues to rise worldwide (OECD 2012): Global water demand is expected to exceed supply by 40% within 20 years (UNEP 2014). By 2030, global energy demand will

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have grown by 40% (IEA 2009), and by 2050, food demand is expected to have increased by 60% (WBCSD 2014); moreover, a high level of consumption of these resources continues to be equated with a good quality of life. This development is contrary to what the founding fathers of the free market economy had imagined: they assumed that when wealth had increased so that everyone could cover important needs, the economy would be sated and stop growing (Keynes 1930; Uchatius 2011). Instead, however, satisfaction with quality of life in countries like Germany has not risen since the 1970s (Uchatius 2011), and ongoing economic growth has served 0.7% of the world's population in amassing 45.2% of global wealth (Credit Suisse 2015), whilst billions of people continue to live in dire poverty and lack basic services.

Cities in developing economies in particular are already facing serious water-related environmental challenges (Marcotullio 2007), as the development of water infrastructure is often unable to keep pace with urban growth. The resulting inadequate access to safe drinking water and management of wastewater causes serious public health risk in cities worldwide (Galea and Vlahov 2005). This situation is being exacerbated by climate change-induced water scarcity and planning uncertainty (Vörösmarty et al. 2000). Cities in the West are also increasingly facing water challenges set to sharpen with climate change: the over-capacity and under-utilization of infrastructure networks resulting from shrinking inner city populations, for example, can cause major problems in technical functioning and economic feasibility (Moss 2008). Yet the paradigm of using water only once remains surprisingly persistent in the face of water-related development challenges (Wilderer 2004; Drewes 2014), in both developed and developing economies. The concept of a flush toilet coupled to a centralized sewage system remains the preferred option and is seen as a symbol of "modernity" and as the "solution that works", despite being very water- and energy-intensive, which is why it has been termed by some as "ecologically mindless" (Narain 2002).

This situation introduces various risks: the greater the consumption of resources including water, energy from fossil fuels, and food, the more CO_2 is released into the atmosphere. Hence, with the lack of adequate climate change mitigation, the predicted impacts of climate change will occur faster and will be more extreme (IPCC 2014). At the same time, the over-dependence on natural resources such as water, energy and food reduces the capacity to adapt to climatic changes such as heat and drought, rendering societies more vulnerable. For example, large-scale centralized sewage systems cannot function with reduced water and energy, leading to blockage of solids and subsequent corrosion of the system, causing public health risk and the need for major investments. The management of water resources is especially critical in adapting to climate change, as this resource impacts almost all aspects of society and the economy (UN Water 2010). With climate change, the equitable distribution of natural resources—and water in particular—will be increasingly important for a peaceful future (Roberts and Finnegan 2003). Water is a finite resource and is essential to human survival. Despite the urgency of this issue, the majority of approaches in both research and practice are aimed at supplying the ever-increasing demand for resources such as water, energy and food, rather than devising the means to reduce it.

In order to enable cities to curb their consumption of natural resources, and hence to avert disastrous climatic change, an integrated urban planning approach is urgently needed. Given the limited capacity of most cities, an approach that leverages potential synergies of climate change mitigation and adaptation strategies is necessary. Further, in order to meet the climate target of less than 2 °C, such an approach needs to be implemented and mainstreamed at a worldwide scale by 2030 (IPCC 2014).

The Water–Energy–Food (WEF) Nexus approach, which has rapidly gained momentum in recent years, is one possible way to effect such integrated urban planning. This approach highlights interlinkages between the water, energy and food sectors, in that it takes much energy to supply freshwater and remove and treat wastewater, and that much water is needed to produce energy and food (ADB 2013). It aims to optimize the water and energy systems in a synergistic manner whilst also optimizing food production. The concept emphasizes responsible governance (GWSP 2014) and that a new perception of water is needed, with the water–food link being of the highest social and political significance (ADB 2013).

However, although many suitable technologies exist, to date there are few operationalized examples worldwide of the WEF Nexus approach at the neighbourhood or city scale. To enable its operationalization, more pilot projects are needed at the neighbourhood scale to serve as a beacon to demonstrate the viability and monitor the efficiency of this approach.

The WEF Nexus approach combines three systems that are each complex enough: water, energy and food. If we consider that the original impetus for public water supply and sanitation was to establish proper hygiene standards to protect public health in the wake of various devastating epidemics in Europe, the WEF Nexus even covers three separate systems whilst still maintaining overall public health protection. The development and current state of each of these systems are path-dependent, and every approach for optimizing one of these systems generates new path dependencies. As the WEF Nexus approach aims to optimize these individual path-dependent systems in combination, it is evident that a particularly high level of complexity with special challenges and risks exists. Furthermore, the WEF Nexus is also connected to other related path-dependent systems, such as solid waste or transportation, which also need to be considered to achieve a holistic approach to the development of a given city.

In this paper, two case studies in very different climatic, geographic, cultural, and economic development zones are juxtaposed and the WEF Nexus approach hypothetically applied to each of them: Leh is a small city with about 60,000 inhabitants in the semi-arid high-altitude Ladakh region of the Indian Himalayas, and Maxvorstadt is a neighbourhood of Munich with a population of about 50,000. Munich is located in the water-rich alpine foothills region of Southern Germany. The two cases are chosen to illustrate key potentialities of operationalizing the WEF Nexus approach, particularly in terms of potential synergies of climate change mitigation and adaptation strategies, and measures of as well as barriers to implementation. The case study in Leh, where there is currently no centralized or large-scale wastewater management infrastructure, aims to show how water consumption patterns in the West can impact and play out at the local level in the context of a developing economy where such centralized water infrastructure is currently being developed. The case study of Munich aims to illustrate the situation where a centralized water infrastructure was implemented around 140 years ago. In both cases, the paper aims to illustrate what an alternative future development could look like and what challenges exist for a more sustainable development approach. The paper summarizes the results of two research projects conducted in 2011–2015, one on Leh funded by the European Commission and the German Research Foundation and the other on Munich funded by the Bavarian State Ministry of the Environment and Consumer Protection.

Methods

For the analysis in Leh, field surveys were conducted in 2012–2015 in collaboration with the Ladakh Ecological Development Group (LEDeG), a local non-governmental organization (NGO). Changes in land use and urban development were mapped using geographic positioning (GPS) and geographic information systems (GIS), a WorldView-2 very high-resolution satellite image (ground resolution 50 cm, DigitalGlobe©, supplied by European Space Imaging) as of November 2011 as a base map, and Google Earth imagery from 2003 as a reference. In addition, a socioeconomic questionnaire survey of 200 households, representing 5% of all households in Leh, a questionnaire survey of approximately 320 guesthouses and hotels, and semi-structured interviews with various local stakeholders were conducted.

For the analysis in Munich, spatial datasets on urban morphology and surface characteristics were provided as 2D polygons (Environmental Systems Research Institute [ESRI] shapefiles) and as a 3D city model (City Geography Markup Language, level of detail 2 [CityGML LOD-2]) by the Department of Environment and Health of the City of Munich and the Bavarian Land Surveying Office. Tabular statistics on population at the block level were provided by the Bavarian State Statistics Department. Spatial statistics were calculated using ESRI ArcGIS and QGIS (www.qgis.org). To retrieve the slope angles of all roofs in Maxvorstadt, the CityGML file was processed in FME (Feature Manipulation Engine, www.safe.com). To calculate facade area, facade length was multiplied by number of storeys, assumed to be 3.5 m each. Facades were simplified by omitting *avant-corps* of <1 m and "filling" gaps of <0.5 m. These values were chosen empirically after iteratively testing values on distortion of the resulting streamlined facades. Orientation of facades was retrieved by calculating the "directional mean" for every facade subsection. Building fronts were grouped by cardinal and intercardinal direction, and surface area was calculated for every class.

Leh, Ladakh, India: A Case Study in a Semi-arid High-Altitude Himalayan Region

Leh is an oasis of green agricultural fields in a quasi-desert in the Ladakh region, a part of the Indian state of Jammu and Kashmir in the Indus Valley. Water is scarce: annual precipitation is only about 10 cm, and snow and glacial melt water is the only available surface water. The apparent lushness of Leh is thus not a natural occurrence, but the result of hundreds of years of extremely careful water management. Until as recently as a few decades ago, Ladakh was still a largely self-sufficient traditional irrigation agriculture society, but since the early 1980s, the number of tourists has increased exponentially, particularly in the last decade: today, around 180,000 tourists visit Leh each year, mostly in the summer months between April and October. In winter there are very few tourists due to extremely cold temperatures. With climate change, increasing uncertainty in the amount of surface run-off from glaciers is expected in Ladakh. Surface water resources are already decreasing, impacting the availability of irrigation water and groundwater recharge.

Over the last few decades, almost 400 hotels and guesthouses have opened in Leh, which are increasingly establishing conventional Western-style water infrastructure concepts including showers and flush toilets to attract tourists. This has driven a rapid rise in freshwater demand and wastewater production. Freshwater is supplied mainly from groundwater aquifers, including the Indus River aquifer, which is very energy-intensive due to pumping and conveyance needs. Leh already faces regular power cuts, with available hydropower being insufficient. With socioeconomic change and less water available for irrigation due to climate change, 30% of agricultural fields have fallen barren, rendering Leh more or less completely dependent on food imports. Leh currently has no systematic wastewater management, with wastewater collected in soak pits and septic tanks that are not properly managed. Because groundwater is a source of drinking water, groundwater pollution through seepage represents a health risk. To address this issue, the local government is currently building a centralized sewage system comprising around 80 km of piping. A central wastewater treatment plant is planned at the foot of Leh, where wastewater is to be treated and discharged to the Indus. Currently, the government aims to provide 75 L of potable water per capita per day (Lpcd). However, in the future, 135 Lpcd will be extracted from groundwater aquifers, and a significant portion will be used simply for flushing the system.

Integrated urban planning using the WEF Nexus concept, with decentralized urban water reclamation and reuse to conserve water and energy for small clusters of hotels, guesthouses and households, could be an alternative development option for Leh. With multiple reclamation facilities, the associated decentralized sewage systems require less water to flush. The reclaimed water could be used locally to regenerate barren land for vegetable production, increasing food security. In off-seasons, it can also be used to replenish the local groundwater aquifer. In order to cover the power demand of smaller decentralized water reclamation facilities, solar energy can be utilized, augmented by the production of biogas, whilst providing water quality tailored to local needs in close proximity to irrigation water demand. Larger facilities could also produce biogas and reclaimed water, but in Leh this would have to be supplied/pumped back to where the demand is, which would require an additional distribution system and a significant amount of energy for pumping. Biosolids containing residual nutrients and organic substances can be used as fertilizer in agriculture. This alternative development option can also generate green jobs locally for operation of the treatment facilities and growing and marketing valuable crops. Given the smaller size, these systems are more flexible and hence resilient to effects of climate change such as reduced water availability.

The project was conducted in close collaboration with the key environmental NGO LEDeG in Leh that advises the local government. Several stakeholder meetings were held where representatives of the local government the Ladakh Autonomous Hill Development Council (LAHDC), including the Chief Executive Councillor and senior advisors, were present. However, plans to implement the centralized sewage system could not be modified because construction had already begun at the time, although many senior advisors favoured a decentralized water reclamation and reuse concept.

The plan for a centralized sewage system in Leh had been under consideration since 2009, when a consultant in Delhi was engaged to design it. The Indian national government granted the funding for the project in 2013. The plan was based on assumptions that may provide challenges in the future: the system was designed for 30 years and a projected population of 80,000. It assumed that all households would be connected to the system and would consume about 135 Lpcd, which is required to flush the system. Customers are expected to pay the service charge to cover operation and maintenance costs. However, only 30% of households currently own a flush toilet, only about half have private water connections, and about only half of these pay their water bills. The cost of connecting to the centralized sewage system and the necessary sanitary infrastructure to consume 135 Lpcd of water is to be borne by the households. Thus, there is a fair degree of uncertainty as to the number of households that will ultimately connect. Energy is seen as the only current bottleneck to the project. Ladakh has leased huge areas of land to the Indian national government for solar energy development, which will also provide a more reliable supply of energy to Leh. Water resources available through the Indus River and its connected aquifer are considered ample as well.

According to government guidelines, in urban areas of India with a centralized sewage system, the government must provide 135 Lpcd of water, of which 35 Lpcd is needed just to flush the system. However, in urban areas without a centralized sewage system, 75 Lpcd is sufficient. In Leh, the LAHDC aims to provide 75 Lpcd but actually provides less due to local power constraints: according to our survey, the local population may be consuming as little as 21 Lpcd. Thus, with the implementation of the centralized sewage system, the LAHDC is essentially encouraging the local population to consume six times as much water as before. This, to many Ladakhis who have been using water extremely sparingly for centuries and are very much aware that they live in a desert, seems preposterous and even immoral.

Ladakh, as a semi-autonomous region, can adapt national policies to its own context. However, water-saving technology alternatives are not readily available. There are almost no case studies of urban water reclamation and reuse at the neighbourhood scale in semi-arid regions. Large-scale infrastructure investment in a centralized sewage system in Leh translates into economic growth, and hence there are many barriers to the operationalization of the WEF Nexus approach, even though it may be a more sustainable development option in theory. However, a central question that many inhabitants are also asking in view of the present development remains unanswered: What will happen in Leh if less water becomes available? Considering this uncertainty, is the implementation of a centralized sewage system sustainable?

Munich, Germany: A Case Study in the Water-Rich Alpine Foothills Region

The city of Munich, the largest city in southern Germany and the capital of the state of Bavaria, has a population of 1.4 million (City of Munich Statistical Department 2014). The Maxvorstadt neighbourhood in Munich, with an area of 430 ha, has a total population of 51,642 and population density of 12,000 persons per km^2, making it among the most densely populated of Munich's 25 neighbourhoods (City of Munich Statistical Department 2014).

Impacts of climate change in Germany are expected mainly in terms of extended periods of drought and heat, as well as changes in precipitation patterns. In Bavaria, it is expected that average temperatures will increase by 0.5–2.5 °C by 2050 and 1.5–4 °C by 2100 (City of Munich, 2014). The number of summer days (max. temp. >25 °C) is expected to increase by up to 19 days by 2050 and up to 43 days by 2100; the number of heat days (max. temp. >30 °C) will increase by up to 9 days by 2050 and up to 25 days by 2100; "tropical nights" will increase by up to 5 days by 2050 and up to 16 days by 2100, and cold days will decrease significantly (StMUV, 2016). Average precipitation is currently 400 mm in the hydrological winter half-year (November to April) and 533 mm in the summer half-year (May to October) (LfU, 2012). In southern Bavaria, where Munich is located, precipitation in winter is expected to increase by up to 11% by 2050 and up to 21% by 2100, and in summer is expected to decrease by up to 7% by 2050 and as much as 17% by 2100 (StMUV 2016). With its high density of five-storey urban blocks as the dominant urban fabric type and a large amount of impervious surfaces, Maxvorstadt is particularly prone to heat island effects and flooding due to excessive rain events. Heat island effects are already affecting Maxvorstadt in terms of public health risk, particularly for elderly people and small children, who are especially vulnerable to heat.

In Munich, current water demand and supply is as follows: the city provides its 1.4 million inhabitants with around 300 million litres of freshwater daily, abstracted from groundwater in the foothills of the Alps and delivered by gravity to the city (SWM 2015). Average freshwater consumption in Munich is 128 Lpcd, of which an average of 35 Lpcd is used for toilet flushing (SWM 2015). If a population of 46,960 (living only in the blocks, and without children under the age of 3 years, who use significantly less water and energy) is assumed, current total freshwater demand in Maxvorstadt blocks is 6010 m^3/day. Of this, roughly 1640 m^3/day or 600,000 m^3/year is used for flushing toilets.

A significant source of water currently not being utilized in Munich is rainwater. If all roof surface steeper than 15° were used for rainwater harvesting, a total of 87 ha of roof area would be available in Maxvorstadt. If an accumulated rainfall of 0.4 m between November and April and of 0.5 m between May and October is assumed, this could result in a total harvested rainwater volume of 783,000 m^3/year. Thus, the total available rainwater volume in Maxvorstadt is sufficient to cover current freshwater demands for toilet flushing, which in theory could enable a reduction in current freshwater supply by 26%. For the hypothetically required storage of this rainwater, it is assumed that most buildings in Maxvorstadt of three storeys or more have a cellar, and that these, along with existing underground parking, could be turned into watertight cisterns relatively easily, but with significant cost and space constraints for other uses. The footprint of these three-storey-plus buildings comes to 913,724 m^2. If the current 50,139 m^2 of underground parking is added, and an average ceiling height of 2.5 m is assumed, this gives a potential water storage capacity of 2,410,000 m^3. That is, to store a whole year's worth of rainwater, 30% of existing underground structures in Maxvorstadt would be needed. There is a well-functioning economic incentive in place in Munich for rainwater harvesting. Property owners are encouraged to unseal impervious surfaces, allowing rainwater to infiltrate the groundwater aquifer, whereby they can save up to 70% of the wastewater discharge tariff, which currently is a combined fee of 1.56 €/m^3 for wastewater and 1.30 €/m^2 for rainwater for sealed surfaces connected to the sewer system (Münchner Stadtentwässerung 2005). Also, Munich has a groundwater aquifer below the city where water can be stored more effectively than in cisterns. However, the incentive to implement rainwater delivery facilities to substitute drinking water for non-drinking water purposes is currently rather low: considering the current tariff for drinking water, the savings by not paying for drinking water would account for less than €4 million/year. Not considered in this scenario are costs for rainwater treatment to meet specific use requirements, the conveyance systems to customers, or pumping energy. In addition, rainwater for percolation into the aquifer must comply with quality standards and is likely to need pretreatment in urban areas. Further, the existing stormwater drainage system must still be maintained and paid for as long as some of the rainwater collected continues to be discharged into the sewer system, such as rainwater from traffic areas. This example illustrates that in cities with an existing fully built-out sewage infrastructure, which is also designed to capture wet weather events, the economic and energy-saving incentives are not highly conducive to implementing a major change in urban water infrastructure. Incentives that merely cover costs would also not be sufficient: additional (economic) incentives would be needed.

In terms of energy, the primary energy consumed in households in Munich is for heating, at 78% (SWM 2014). Current total consumption per person of electricity in households in Maxvorstadt is estimated to be 1800 kWh per year (SWM 2015-2). Of this, about 715 kWh per person per year is needed to provide hot water, 585 kWh for food refrigeration, 195 kWh for electric cooking, 195 kWh for lighting, and the remainder for other electrical household appliances (SWM 2014).

At Jenfelder Au, a newly built neighbourhood in Hamburg, Germany, and home to 2000 people, a different water management concept was established, wherein the collection of blackwater (from toilets) and greywater (from kitchens and bathrooms) from households is separated. Blackwater is mixed with organic waste to generate biogas, which is re-supplied to households for heating and other energy demands. The residues from the greywater treatment are also fed into this process, and the clean water channelled to water bodies in the landscape. The process generates 340,000 m^3/year of biogas, which after transformation yields 370 kWh/person*year of electricity and 778 kWh/person*year of thermal energy (Schönfelder et al. 2013). If one were to apply the same process to Maxvorstadt, in theory, the same energy savings per person are possible, and biogas production could reach 7,983,200 m^3/year. Thus, a significant amount of local household heating and electrical energy demand could hypothetically be met through decentralized energy production using domestic sewage mixed with biomass such as organic kitchen waste. Saving the water used for flushing toilets, as described above, by using rainwater can also enable energy savings of 5.5 kWh of electricity per person per year for the Jenfelder Au development (Schönfelder et al. 2013). However, in Munich, where the favourable topography obviates the need for pump energy to supply drinking water, the energy needed to pump rainwater from underground cisterns or the groundwater aquifer to the top of buildings for toilet flushing could well exceed any energy saving. An energy-saving incentive may be more attractive to households than costs saved due to conservation of drinking water. Considering the current energy rates in Munich, however, it may be difficult to convince households and homeowners to invest, as such a use would require a dedicated dual distribution system, which would be very expensive to implement in existing buildings. What is more, parallel distribution systems come with some risk of faulty cross-connections. However, retrofits might become more economically viable in combination with energy conservation measures or restorations.

In terms of food, the current practise of urban agriculture is negligible in Maxvorstadt. For this case study it was hypothesized that to most effectively cool the microclimate and avoid an urban heat island effect, both today and in the future under climate change, as much green infrastructure as possible would need to be integrated into the urban fabric. In this study, based on the WEF Nexus approach, this is surmised to be intensive urban agriculture. However, other types of green infrastructure could be used to cool the microclimate effectively. There is a significant amount of haphazard building development inside the Maxvorstadt block courtyards, owing amongst other factors to acute housing shortage in the wake of

World War II. Buildings of less than three storeys inside blocks were assumed to be non-residential (e.g. garages) and were hence hypothetically eliminated without decreasing population density. It was further assumed that impervious surfaces inside blocks could be unsealed if a trend towards decreasing car ownership were assumed, as these are mainly car parks. These freed-up areas could be used for urban agriculture. Also, it was assumed that flat roofs and those with less than a 15° angle, as well as southwest-facing facades (except of landmarked buildings), were suitable for horizontal and vertical urban agriculture. Obviously, these net areas identified cannot all be used for urban agriculture, as shading and space needed for other activities have to be considered. But for the sake of simplicity, here, the net horizontal and vertical areas are assumed to be available for urban agriculture. This represents a total area of 168 ha, with an irrigation demand of 1840 m^3/day in the growing season between May and October.

In Bavaria, due to the abundance of water resources, there is no systematic data collection on crop irrigation: when crops need irrigating, water is simply applied. Much of the irrigation demand is currently met by rainfall, unless the summer is dry and hot, as was seen in 2003 and 2015, in which case vegetables must be watered regularly (LWG 2015). Hence it is necessary to plan for urban agriculture irrigation in view of the expected increase in warm days and the significantly reduced summer precipitation during the planting season, as described earlier. Stored rainwater or reclaimed water could hypothetically be used in Maxvorstadt for this application, but only after very cost-intensive treatment, including disinfection, to make it safe for reuse.

Although exact figures are missing, recovery of energy from wastewater is practised in approximately 30% of all wastewater treatment plants in Germany. These facilities convert the biogas generated to energy and heat, providing on average 80% of their energy demand and approximately 10% of their heating demand (Statistisches Bundesamt 2015). Biomass is generally considered CO_2-neutral and can be stored, as opposed to other regenerative sources such as wind or solar energy. Munich currently has two wastewater treatment plants that use co-digestion to generate biogas, which is converted to supply 78% of their energy demand (with projected upgrades to cover up to 90%) and more than 100% of their heating demand. In comparison, the efficiency of a multitude of decentralized smaller-scale wastewater treatment plants in various parts of the city may be much lower. Biogas generation has been supported by the political agenda in Bavaria in the past, but only from crops and animal manure (StMWIVT 2011). Recently, biogas from energy crops has become less politically popular: it is the most expensive renewable energy and comes with significant environmental degradation (e.g. erosion, pesticide use). Incentives for the use of biomass as renewable energy are currently restricted to the agricultural sector in Germany, which is a barrier to promoting increased generation of biogas in municipal wastewater treatment plants. In fact, there is even a disincentive in place for wastewater treatment plants to feed electrical energy from biomass into the grid (German Renewable Energy Law 2016). Nonetheless, in Bavaria, research into biogas generation from wastewater has been conducted for decades. Further, municipal wastewater continues to be a very stable resource in cities. Renewable energy is the primary job creator in Germany (The °Climate Group 2007), and decentralized energy generation using wastewater and biomass can create further jobs. Biomass from urban agriculture such as cuttings and stems and from household organic waste can be added to municipal sewage to enhance local biogas production. Currently, roughly 28 kg per person of organic waste is collected each year in Munich in so-called bio bins, but the full potential is assumed to be 93 kg per person if all organic waste were to find its way into these bins (AWM 2015). Hence, organic waste, if systematically harvested, is also a valuable potential resource that is currently being under-utilized in Munich.

At Jenfelder Au, the investment needed to generate energy from the blackwater of 2000 persons using a fermenter, heat exchanger, sludge thickening process and cogeneration plant was €935,000 (Schönfelder et al. 2013). If the same plant size to generate energy decentralized for 46,960 persons over the age of 3 years living in Maxvorstadt blocks is assumed, 23 plants will be needed. These resource recovery facilities are hypothetically installed underground to enable collection of wastewater by gravity in the block courtyards: rainwater is channelled to flush toilets by adding a pipe in existing shafts, and blackwater is collected by disconnecting the toilet pipe from greywater pipes. Using plants of the Jenfelder Au type, total investment in the plants would only be around €20 million. With 136 blocks, one plant per block may be more sensible in order to avoid pipes below roads. In that case, the total investment would be around €130 million. However, at Jenfelder Au, this cost was for development on a greenfield site. Thus, the cost to install the same infrastructure for source separation in Maxvorstadt, an existing urban setting, would be much higher. In addition, costs for installing pipes and pumps, and operational and maintenance costs, would also need to be considered.

The central sewage system of Munich is 2500 km long, and the cost of the redevelopment of a 1.6-km section was recently estimated at €26.5 million (SZ, 2014), or €16 million/km. The cost is high because this segment of the sewage system is particularly old and of a particular type of construction. Nonetheless, using this cost as the basis for a rough estimation, renovation of the system for the area of the Maxvorstadt blocks, which comprises about 25 km, could cost around €400 million.

However, implementing the WEF Nexus-based scenario as described above in Maxvorstadt would entail huge investment at the household and municipal levels: provisions would also have to be made to store rainwater and reclaimed water during the non-growing season. Further expense would be involved in ensuring appropriate quality in terms of health and safety of reclaimed water for reuse, installing the new systems required to harvest bio-energy, adapting existing systems, and distributing the reclaimed water and harvested bio-energy to the designated demand locations, including pumping energy. The cost of implementing and operating urban agriculture at a large scale would be significant as well. A large set of individual plants and separate systems would also entail huge additional operational and maintenance costs. Finally, complicated socioeconomic, land ownership and administrative issues would need to be tackled, incurring further costs.

Hence, transitioning to an alternative system in Munich is not economically attractive. Further, the conversion or redesign of such large-scale existing infrastructure and planning conventions would require a considerable amount of time. It would also have to be proven that energy savings, in particular, would be more than marginal. If we compare this scenario to what Munich is already doing, the water- and energy-saving incentive for the municipal government to adapt the existing system in a neighbourhood like Maxvorstadt is very limited. In a new development such as Jenfelder Au on a green- or brownfield site, the cost calculation is completely different, making water reclamation and reuse potentially much more viable. However, in an existing neighbourhood of the urban fabric type of Maxvorstadt, the costs far outweigh the benefits.

Nonetheless, the fact that the centralized sewage system is in need of expensive large-scale renovation, along with its strong path dependence, is a "window of opportunity" to think about other technological solutions in view of future climate change-related water challenges, and to use these thoughts to support a paradigm shift. At the moment, decentralized water recycling is much less economical than the centralized sewage system if a time frame of 20 years is considered (Sedlak 2015). Yet, what if we look at the next 100 years and factor in the cost of providing sufficient freshwater for current demand over great distances to cities in water-scarce regions? Munich is a special case, where freshwater provision requires relatively little energy. In contrast, cities like Sao Paolo in Brazil are already experiencing the burden of such costs. In the United States, the cost of restoring existing water systems that are falling into decay is estimated to be at least $1 trillion over the next 25 years (AWWA 2012). If more pilot projects are built now, the long-term benefits of more flexible decentralized water reclamation and reuse schemes tailored to local needs could be determined. In Munich, just as in Leh, there are many potential barriers to the operationalization of the WEF Nexus approach. Key questions to consider for future development of Munich are: Is maintenance of the existing infrastructure sustainable? Which type of infrastructure may be suitable for new parts of Munich that are now being planned?

Synthesis of the Two Cases

This paper has aimed to illustrate that under climate change-related water uncertainty, implementation of natural resource-intensive technologies such as traditional water supply and sanitation systems may carry risk of failure, considering current and future boundary conditions. Implementation of all technologies is path- and resource-dependent, and hence implies risk. However, some technologies can be more flexible and thus more resilient to changing conditions than others. These uncertainties are currently also reinforced by the lack of clear policy intent to curb consumption of natural resources such as water, energy and food. Hence, the question of how to reduce consumption to mitigate and adapt to climate change, and particularly to conserve water resources, is just as urgent in the West as elsewhere.

There are many viable water reclamation and reuse technology options available. Implementing these in some urban fabric or city types may inherently support the conservation of water and energy resources and increase the system's overall resiliency. However, thus far, these technology options have rarely been implemented at scales larger than individual buildings or single service providers. Additional pilot projects are needed to test the efficacy of these options, for example, at the neighbourhood scale. There is a large volume of data regarding conventional large-scale systems and energy efficiency, but virtually no such data to enable a comparison of smaller-scale options. Research is needed to address questions such as the amount of energy that could be recovered through a WEF Nexus-based approach as described here, in Leh as in Maxvorstadt, and whether this could be as efficient, in order to support implementation efforts.

In order to assess whether a WEF Nexus-based alternative development option is suitable for a given location in terms of the so-called triple bottom line, i.e. social, environmental/ecological and economical aspects, a thorough study of a given city's boundary conditions is needed. Decentralized options may not be best for some types of cities (Wilderer et al. 2016). In the case of Munich, the city is already engaged in the conservation of water and energy resources. A radical change to the existing system, for example, as described above, could harbour unintended consequences that are difficult to foresee. However, there may be other types of neighbourhoods in existing cities where this would not be the case. For example, in Germany these might be cities where populations are shrinking or ageing and water consumption patterns are changing, or urban fabrics that are in need of large-scale renovation due to low building quality, such as neighbourhoods constructed in the post-World War II era. In developing economies, these could be cities where water infrastructure development is unable to keep pace with urban growth. An alternative development option may also be suitable as an add-on in certain contexts in a semi-central or hybrid approach, for example, where a centralized sewage system already exists but there are areas of the city that are not being serviced by it. A catalogue of key indicators coupled with reliable numerical values might help to determine the suitability of these boundary conditions. Such a catalogue might be structured to address various key questions, examples of which are described in Table 7.1.

This study has many limitations, as it is very hypothetical and makes many assumptions. However, the main aim of the study was to indicate potentialities for operationalizing the WEF Nexus approach. As such, it advocates that a thorough investigation into such potentialities is warranted.

Conclusion and Recommendations

The WEF Nexus approach cannot be dismissed as a "development topic". A paradigm shift is urgently needed to enable the broader implementation of water reclamation and reuse, resource recovery, and sustainable food production—

Table 7.1 Aspects that influence the choice between centralized or decentralized (sub)systems or acceptance (of change to existing systems)

Key question	Key indicators
1. Which resources predominantly trigger supply needs/abilities?	Climate; geographical and regional differences; water, energy and food demand; supply and availability; history and trends; ethics/religion
2. What are the components of the existing water management system?	Relative location of water supply sources, topography, distribution and storage system, sewage system, existing legislation and by-laws, existing infrastructures and construction features
3. How acceptable is a different system to the local community?	Awareness; socioeconomic indicators on income, education, health
4. How can a modified or new system be administered?	Existing institutions, legal and regulatory framework, policies, budget
5. What would be the necessary material and financial investment?	Financing, cost-benefit analysis, existing resources e.g. for construction

centralized or decentralized—in existing cities. Here, actions by local city and national governments are crucial. When water, energy and food were scarce in the past, national and local governments were very stringent in curbing consumption of these resources by local populations, for example during the first oil crisis. Today, such action is urgently needed to help propel the plethora of existing bottom-up initiatives. To meet the climate target of less than 2 °C, government action on climate change needs to become a key aspect of welfare capitalism within the next few years.

In the future and under climate change, the question of water availability will be critical in identifying the appropriate type of water management infrastructure for urban development at a given location. Water availability, however, cannot be precisely predicted, and forecasting is even more uncertain under the impacts of climate change. Hence, it is imperative that when windows of opportunity open for the construction of new infrastructures or for renovating and modifying existing ones, these infrastructures must be planned to conserve water resources to the fullest extent possible in order to support the resilience of cities against climate stresses. If we had known then what we know today, we might have designed the mainstream water management systems constructed over a century ago to better conserve water and energy resources. As it is, the focus of urban water infrastructure provision has changed over the last decade, from one focused solely on hygiene, towards a Nexus-based approach, including recovery of energy and nutrients such as phosphorus. Today, existing systems are diluting a very valuable resource, namely municipal sewage, to such an extent that it is difficult to recover its intrinsic energy content. Modifying existing systems requires a long-term planning horizon to adapt city design (taking future developments in terms of climate change into account). Both case studies hint towards the need for supporting tools such as economic incentives, refinancing regulation, cross-sector balance and expert appraisal in order to assist various aspects of change.

Path dependency, meaning loss of flexibility when choosing a system for a water infrastructure, becomes a risk when boundary conditions change, such as changes in population or climate. This risk is expected to decrease when interdependencies of water infrastructure with other sectors such as energy or food are more closely taken into account when a window of opportunity opens for implementing new or modifying existing water infrastructure.

A catalogue of key indicators coupled with reliable numerical values to describe boundary conditions can support taking rational decisions. These decisions should not be hamstrung by path-dependent developments in the water, energy and food sectors, as they have been in the past, but instead must acknowledge and utilize the synergies for an integrated development of all three sectors. To a certain extent, decision-makers will always have to rely on their instincts and common sense. Incentives for taking sustainable decisions must also extend beyond economic considerations, to visions of a desirable future for generations to come.

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