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Saving water in cities: Assessing policies for residential water demand management in four cities in Europe

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ABSTRACT

Policies for water demand management (WDM) have evolved in recent decades as an important strategy to reduce water consumption in cities. The objective of this study is to identify what WDM policies have been most effective, based on the perspectives of water utilities and experts. To this end, four cities with a low per capita residential water usage were identified: Berlin, Copenhagen, Tallinn and Zaragoza. A mixed-methods approach, including a questionnaire for water utility officials, semi-structured interviews, and review of secondary data and information, was used to identify successful policies. Results show that residential consumption from 1995 to 2015 has reduced in all four cities, irrespective of which policies were perceived to be more or less effective, though savings have been larger for cities with a larger number of perceived effective policies. WDM policies rated as highest-impact were renovation and maintenance of networks, and campaigns for water-saving technologies, followed by universal installation of water meters, rapid leak detection, public awareness campaigns, and municipal regulations. Tariff reforms were mentioned as impactful only in one case. However, lowering the level of urban water use by too much may lead to technological and financial challenges for water utilities.

1. Introduction

Managing scarce water resources in an efficient, effective and sustainable manner is an essential public service challenge for cities (Brown, Keath, & Wong, 2009; Grafton et al., 2015; OECD, 1999, 2008, 2016). Cities are particularly vulnerable for water scarcity as a spatial mismatch of available freshwater resources and population concentrations – rather than an overall lack of water resources – can lead to supply challenges. Population growth, increasing urbanization, climate change induced droughts and rising temperatures exacerbate the situation, leading to the risk of depleting reservoirs and reduced groundwater recharge.

In Europe, at least 11% of the population and 17% of its territory have been affected by water scarcity since 2007, and this is expected to increase due to climate change (EC, 2016). At the municipal level, the cities need to address water management and governance challenges for too much, too little, and too polluted water. Among 48 – predominantly European – cities surveyed in a recent OECD (2016) study, the key challenges to effective water governance were: ageing or a lack of infrastructure; national laws and regulations; extreme events; climate change; water pollution; and a lack of attention of water on the political agenda. Most cities also mentioned urban growth and growing populations as problems, while a minority identified shrinking populations as a challenge.

In this context, water demand management (WDM) has emerged as an important policy response to water scarcity and environmental sustainability concerns in Europe and elsewhere. Many cities have implemented WDM policies to reduce consumption to more sustainable levels (Arbués, García-Valiñas, & Martínez-Espiñeira, 2003; Grafton et al., 2015; Hughes, Pincetl, & Boone, 2013; Inman & Jeffrey, 2006; Renwick & Green, 2000; Willis, Stewart, Panuwatwanich, Williams, & Hollingsworth, 2011). The objective of this study is to assess the effectiveness of these policies, based on the perceptions of water utilities and experts, in reducing household use in four cities with low per capita residential water consumption: Berlin, Germany; Copenhagen, Denmark; Tallinn, Estonia; and Zaragoza, Spain. The next sections provide a conceptual overview of WDM, related policies in Europe and their impact on reducing residential water use, and present research results on the perceived effectiveness of individual policies in each city, including subsequent analysis with additional information from interviews and secondary research. Lessons learned are of particular interest to municipal policy makers, city planners and utility managers in the water sector.

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2. Water demand management: concepts, policies, impacts

2.1. The conceptual basis for water demand management

For most of the 20th century, water demand management (WDM) received little attention. Water planners simply calculated future water use by multiplying expected use per capita with population to be served. Water infrastructure, such as reservoirs and pipelines, was then constructed to store and transport the quantity needed (Gleick, 2000).

In the 1970s and 1980s, however, a combination of factors led planners to rethink their narrow focus on supply-side management: (1) fewer untapped water resources near cities while those remaining became more difficult to access; (2) contaminated and/or depleting groundwater resources further limiting available supply; (3) increasing droughts and more intense competition between urban, industrial and agricultural water users; (4) a rising awareness about the environmental costs of large-scale water infrastructure developments; (5) increased public understanding about the interdependence of water, a functioning ecosystem, and human health; and (6) high costs of constructing and maintaining water infrastructure decreasing the enthusiasm for investments from water agencies (Baumann & Boland, 1998; Gleick, 2000, 2002). The result was a shift from focusing on tapping unused water resources to new ways to meet water needs with less resources, at a lower cost, and with less ecological deterioration.

The conceptual basis of WDM is water conservation, i.e. any beneficial reduction in water use or in water losses (Baumann & Boland, 1998). Thus, managing water demand also implies changing individual and organizational behavior towards more sustainable usage patterns. Brooks (2006) provides an operational definition: WDM is any measure – administrative, economic, financial, technical, or social – that achieves one or more of the following five objectives: (1) reducing the quantity or quality of water required to accomplish a specific task; (2) adjusting the nature of the task so it can be accomplished with less or lower quality water; (3) reducing losses in movement from source through use to disposal; (4) shifting time of use to off-peak periods; and (5) increasing the ability of the system to operate during drought.

Water quality is an important element of the WDM concept, as it directly affects the quantity of potable water. For example, using non-potable water for specific tasks can leave more freshwater resources available for other uses. Similarly, reducing water pollution also helps to increase the amount of water available for potable uses at any given time.

From a governance perspective, WDM has been described as a policy framework aiming at limiting water use to the amount that meets the socioeconomic needs without squandering resources, at reasonable cost and without stripping other areas and future generations of critical natural resources (Bithas, 2008). The sustainability aspect of WDM is stressed, i.e. not using (or polluting) more water than can be treated for future use. Also, a combination of different policies is considered necessary to ensure efficient, non-wasteful water use, limit environmental deterioration, and charge adequate fees, thus balancing the need for cost recovery with equality and ecological concerns.

2.2. Water demand management policies in Europe: Water Framework Directive (WFD)

The Water Framework Directive (WFD) shapes demand management policies in cities in the European Union (WISE, 2008). Ratified in 2000, it promotes a set of policies to achieve more efficient use among water users. Its main objective is to ensure water quality, i.e. to achieve good ecological status in all waters (Alcon, Martin-Ortega, Berbel, & de Miguel, 2012; Meyer & Thiel, 2012). Key goals are to manage the interrelated challenges of water scarcity, quality deterioration, and managing costs for water supply services, including full cost recovery. Governance solutions focus on sustainable water use, facilitated by demand management policies and innovative cost recovery pricing for water services (Bithas, 2008).

Specific policy and analytical tools to address water scarcity include pricing policies for cost recovery, taking into account the "user pays principle"; new investment projects; new regulations; and negotiated agreements with polluters. Cost-effectiveness and cost-benefit analysis help identify most effective policy alternatives, and ensure public funds are well spent. Since the largest users of public utility water are households (Eurostat, 2012), demand management policies and tools have been implemented by a number of municipalities in Europe to reduce residential water demand.

By encouraging a rational use of water, including criteria of efficiency and savings, the WFD illustrates the strong linkage between managing water quality and quantity. It calls for reducing water consumption, recycling and reusing water wherever possible, minimizing pollution, and treating wastewater properly.

2.3. Water demand management policies in cities: impact on residential water use

A review of the literature on WDM reveals that policies fall into two main categories: tariff measures include water price increases or tariff reforms, while non-tariff measures take the form of operational improvements, regulations and restrictions, information campaigns, and technological innovations (Inman & Jeffrey, 2006; Jorgensen, Graymore, & O'Toole, 2009; Olmstead, Hanemann, Stavins, & Kennedy, 2003; Olmstead & Stavins, 2008). The effectiveness of policies and tools varies significantly depending on the context they are used in. For an overview of the impact of different policies found in the literature, see Table 1.

2.3.1. Tariff policies

One key insight is that indoor water demand appears to be largely inelastic to price (Arbués & Villanúa, 2006; Domene & Saurí, 2006; Inman & Jeffrey, 2006; March & Sauri, 2010; Olmstead et al., 2003; Olmstead & Stavins, 2008). Hence, policymakers' ability to reduce household consumption through tariffs seems limited. Yet, three considerations deserve attention. First, the studies show that in the United States, price responsiveness – while varying significantly depending on place and time – averages 3–4% of urban residential water use reduction for every 10% price increase, hence, there is some response. Second, the same studies show that long-term price elasticity for households is somewhat larger, at 6% reduction for 10% increase. Third, as a consequence, the effectiveness of water tariff reforms is largely variable depending on context and location. For example, price elasticity has been shown to be higher in Europe than in the United States, allowing for different policy responses (OECD, 1999, 2008).

2.3.2. Non-tariff policies

2.3.2.1. Operation and regulation. Leakage detection and repair of the utility's water infrastructure is considered one of the most effective policies, and thus a policy applied in various cities intent on reducing their water consumption and non-revenue water (Inman & Jeffrey, 2006; Kayaga & Smout, 2014; OECD, 2016; Tortajada & Joshi, 2013). Note that these measures do not strictly affect per capita water consumption, but they are commonly included in WDM policies. Plumbing codes and water efficiency labeling – voluntary or compulsory – lead to water savings, e.g., 5–10% in Australia and the U.S. (Inman & Jeffrey, 2006). Water restrictions are usually only applied in areas facing serious droughts. In this case, specific purposes of water (i.e. outdoor use) are curtailed or prohibited, or water availability may be restricted to certain times. While restricting water use can lead to significant water savings, its effectiveness depends upon residents following the policy, which can be difficult to enforce (Olmstead et al., 2003; Olmstead & Stavins, 2008).

2.3.2.2. Raising awareness. Several studies show that attitudinal factors

Table 1
Overview of WDM policies and impacts.

Policies	Impact
1. Tariff measures	
Water price	- Water consumption tends to be inelastic to price [1, 3, 4, 8, 9, 10, 11, 12] - Higher water prices reduce water consumption [1, 3, 4, 8] - "Off-setting effect": Reduced water consumption due to price increase tends to decrease after time, and might rise to a higher level than before the intervention [6] - Water consumption is price-inelastic up to a threshold (for basic needs, hygiene and cleaning), while any further water quantity is price-sensitive [3, 10] - Awareness of water price affects water consumption [9]
Tariff structure	- Smart tariff structures, i.e. block pricing, reduce water consumption [8, 11] - However, improving fairness or efficiency of a tariff often makes it more complex and more difficult to understand [4] - Block pricing in developing countries often leads to inefficient results and promotes inequality [16]
2. Non-tariff measures	
Leakage	- Reducing water network infrastructure leakage considered one of the most effective WDM measures [4, 8]
Plumbing codes/efficiency labeling	- Reduced water consumption by 5–10% over 10 years in Australia and US [8]
Restrictions	- Reduced water consumption between 25 and 35% in California and Greece [8] - No effects in one town in Texas [8] - Restrictions were not followed by more than 50% of customers in drought-affected California [12]
Metering	- Metering produces water savings of 10–25% due to information, publicity and leakage repairs [4] - Average of 20% water consumption reduction in US programs [8] - Reduction of 11 l per capita/day in Southeast Queensland [5] - Reduction of 10–15% for households billed according to meter in UK [14] - Metering raises citizens' awareness for the need of water conservation [4, 8] - Secretly installed metering has no effect on behavior [8]
Billing	- Frequency of water billing affects water consumption [11, 15] - Price elasticity increases by 30% or more when price information is posted on water bills [6]
Public awareness campaigns	- Information campaigns are considered important for encouraging more rational water use [4] - Media broadcasts etc. are generally expected to reduce demand by 2–5% temporarily [8] - Effectiveness unclear: water reduction ranges from 0 to 8% in different contexts [8]
Water-saving appliances	- Certain domestic water-saving devices (e.g. low-flow toilets, showerheads and faucets) and certain garden irrigation significantly reduce water consumption [4, 8] - Significant water savings through introduction of low-flow shower heads [4, 12] - Significant water savings through introduction of low-flushing toilets [4, 6, 12] - Indoor water use in the US can be reduced by 9–12% through "retrofit" programs, or by 30–50% through comprehensive replacement of household appliances with more highly efficient appliances and fixing previous (toilet or other) leakages [8] - "Off-setting effect" of water appliances: reduced water consumption dissipates over time [2] - Up to 50% in energy and water savings due to higher standards of modern washing machines, provided full capacity use (full loads) and lower washing temperature [13]

Sources: [1] (Arbués & Villanúa, 2006); [2] (Campbell, Johnson, & Larson, 2004); [3] (Domene & Saurí, 2006); [4] (EEA, 2001); [5] (Fielding et al., 2013); [6] (Friedman, Heaney, Morales, & Palenchar, 2011); [7] (Gaudin, 2006); [8] (Inman & Jeffrey, 2006); [9] (Messner & Ansmann, 2007); [10] (March & Sauri, 2010); [11] (Olmstead et al., 2003); [12] (Olmstead & Stavins, 2008); [13] (Pakula & Stamminger, 2015); [14] (Parker & Wilby, 2013); [15] (Schleich & Hillenbrand, 2009); [16] (Whittington, Nauges, Fuente, & Wu, 2015).

have an impact on water consumption, though somewhat lower than other sociodemographic variables like household size or income (Domene & Saurí, 2006; Gilg & Barr, 2006; Willis et al., 2011). While public awareness campaigns show few signs of lasting behavioral change (Inman & Jeffrey, 2006), introducing water meters can raise awareness about water consumption and the need of conservation and has reduced water usage rates by up to 25%, based on studies across Europe (EEA, 2001). Making water tariffs more transparent through clearer and more frequent billing procedures also affects consumption, increasing price sensitivity by 30%, based on a study across the USA (Gaudin, 2006).

2.3.2.3. Technological innovation. Using water-efficient devices has shown to significantly reduce household water consumption. Technological innovations include low-flow shower heads; low-flush toilets; and water-saving washing machines (Friedman et al., 2011; Inman & Jeffrey, 2006; Olmstead & Stavins, 2008). While retrofitting programs have saved 9–12% of water in US households, comprehensive replacement of household appliances enables three to five times higher water savings, in part due to leakage repair from previous old appliances. However, an off-setting effect of these innovations – i.e. lower consumption yet longer or more frequent usage – makes part of the water savings dissipate over time (Campbell et al., 2004; Inman & Jeffrey, 2006).

3. Methodology and city selection

For the assessment of WDM policies, four cities were selected, according to low domestic water use; population size; comparable socio-economic development levels; data availability; and willingness to provide information. All four cities identified are located in Europe. They are: Berlin, Germany; Copenhagen, Denmark; Tallinn, Estonia; and Zaragoza, Spain.

A mixed methods approach combining quantitative and qualitative data collection was used to identify WDM policies implemented, and to assess their impact. The main focus was on policies and their effects on water consumption as perceived and evaluated by water utilities. A questionnaire was provided to each water utility on water use and tariff development from 1995 to 2015, requesting rating the relative impact of policies. Thirteen individual policies – both tariff and non-tariff-policies – were subsumed from the literature review and presented to recipients. Additionally, semi-structured interviews were conducted with water utility officials and other water experts in all four cities between July and September 2016. Interviews focused on how the respective water sectors evolved over time, what policies and other factors explained reduced water demand, and lessons learned. Further information came from case studies, sustainability rankings, and academic literature.

An important caveat in the study is that care should be taken when comparing cities and policies with each other. Water supply data at a city level is not always available, different sources may provide conflicting data and there is no agreement on common definitions of, for instance, household consumption (OECD, 2016). Similarly, the results of the questionnaires and interviews are self-assessments, based on water utility managers' and other experts' perceptions. Hence, the aim is not to compare the performance of the cities (as utilities benchmarking themselves against others would do) or to state a simplistic quantitative cause-effect relationship, but rather to assess what policies are considered to have made a significant contribution to low domestic consumption in each city's context.

4. Four cities

4.1. Water resources and utilities

Berlin is Germany's capital and, with 3.5 m inhabitants, its most populous city. It features a temperate seasonal climate, with warm summers and cold winters. Total annual rainfall amounts to 570 mm (World Meteorology Organization - Programme World Weather Information Service (WWIS), 2016). Despite its relatively low precipitation levels, Berlin is in the beneficial position to be able to draw from an extensive water aquifer underlying the city, part of the Berlin-Warsaw glacial valley formed more than 10,000 years ago. This ensures the city has good quality groundwater for almost all of the city's potable uses (Salian & Anton, 2011). Berliner Wasserbetriebe (BWB) has been Berlin's water supplier for more than 150 years. Seven years after the merger of East and West Berlin's water utilities in 1992, Berlin's Senate decided to partially privatize BWB, transforming it into a public-private partnership for more than a decade. It was re-municipalized in 2013 and is now again fully owned by the city of Berlin. 70% of its water is sold to domestic, 30% to non-domestic users (Berliner Wasserbetriebe, 2017).

Copenhagen is Denmark's capital and largest city. With 1.3 m inhabitants in its urban area, it comprises almost 25% of the country's total population. The low-lying coastal city has a cold and temperate climate, and annual rainfall of 525 mm (WMO, 2016). HOFOR (Greater Copenhagen Utility) is Denmark's largest water utility, serving 1.1 m customers, or about 90% of Copenhagen's population. It formed by eight municipalities merging their respective water utilities to share water supply and sanitation services; 73% of the company is owned by the city. About 70% of water provided is for household use. Only 4% of the raw water used comes from within the city's administrative borders, as nearly all water is imported from other municipalities (Brears, 2017). As Copenhagen's municipal government serves as HOFOR's regulator, any price change needs to be approved according to the stated non-profit principle, requiring HOFOR to balance revenues and expenditures over time (HOFOR, 2017).

Tallinn, with its 440,000 residents, is Estonia's capital and, comprising a third of Estonia's population, the country's largest city. It has a humid continental climate with warm, mild summers and cold, snowy winters. Annual rainfall amounts to 690 mm (World Meteorology Organization - Programme World Weather Information Service (WWIS), 2016). Tallinna Vesi (Tallinn Water) is the largest water utility company in Estonia, and the only private operator among about 200 water utilities in the country. The municipality holds about one third of its shares. With 22,000 contractual customers and approximately 435,000 end customers in Tallinn and surrounding areas, it provides water and wastewater services to 90% of Tallinn's residents. Almost 90% of Tallinn's drinking water is sourced from surface water, in particular from nearby Lake Ülemiste, while 10% of water users use regional ground water sources (Tallinna Vesi, 2017).

Zaragoza, located in a semi-arid area in the North-East of Spain, has a population of 650,000 people, which makes it the fifth-largest city in Spain according to population. Climate is warm and temperate, and features a total annual rainfall of just 320 mm (World Meteorology Organization - Programme World Weather Information Service (WWIS), 2016). The city largely relies on the Ebro River, which has provided water for agricultural, domestic, and other purposes since Roman times. Zaragoza's central water supply element is the Imperial Canal of Aragon, constructed in 1784 (Celma, 2011). Additional water sources are transported from the Yesa reservoir in the Pyrenees Mountains. The municipal authority provides all water services – water supply, sewerage, and wastewater treatment – directly, through departments that are part of the larger overall city administration. Thus, the Infrastructure department is responsible for operating and maintaining the city's water and sewerage infrastructure, while the Treasury handles water billing and tariff collection, next to their other respective municipal responsibilities (Celma, 2011; Smits, Bernal, & Celma, 2010).

4.2. Water challenges

The selected cities face a variety of different challenges in their water sectors, in terms of quantity and quality. Zaragoza faced significant water shortages due to extensive droughts in the 1990s; public anger resulting from water restrictions was one of the main drivers for water sector reform (Philip, 2011). Copenhagen, due to its geography, also has scarce water resources, and is highly dependent on water transfers from outside its municipal borders.

In Berlin, Copenhagen and Tallinn, the risk of water pollution has emerged as a serious challenge in recent decades. Exposure to harmful pesticides and/or nitrates from intensive agriculture, and industrial discharges can pose a significant threat to available freshwater resources, both surface and groundwater. Accordingly, water pollution has the potential to intensify water scarcity by reducing available potable supply.

In Berlin, the wells for drinking water are located along the city's riverbanks. Thus, it is important to ensure high quality of wastewater and stormwater treatment, in order not to risk polluting the municipality's overall water supply. Emerging contaminants are a growing problem for wastewater treatment. In Tallinn, domestic and industrial discharges contributed to pollution until the 1990s. Protecting water quality is essential as the vast majority of Tallinn's supply comes from nearby surface waters. In Copenhagen, chemicals, pesticides and nutrients from intensive agriculture are constant threats to its groundwater sources, which has already forced the city to close down some of its wells.

In Zaragoza, point pollution is less of an issue, but non-point pollution through nitrates from farming is increasing. Also, the Ebro River's water has a relatively high dissolved saline content as part of its natural make-up, while water quality parameters from Yesa reservoir are much better. Thus, the share of reservoir water used for the city's water supply is increasing (Celma, 2011).

5. Results

5.1. Overall results

All four cities selected for the study show lower than average water consumption, ranging from 113 Lpcd (Liters per capita per day) in Berlin and 104 Lpcd in Copenhagen, to 96 Lpcd in Tallinn and Zaragoza (see Fig. 1). For comparison, the average domestic water usage of 25 cities in OECD member countries in 2012 was 182 Lpcd (OECD, 2016). All cities show clearly decreasing trends, with per capita water demand savings of 10% (Berlin since 1995), 22% (Copenhagen since 1995),

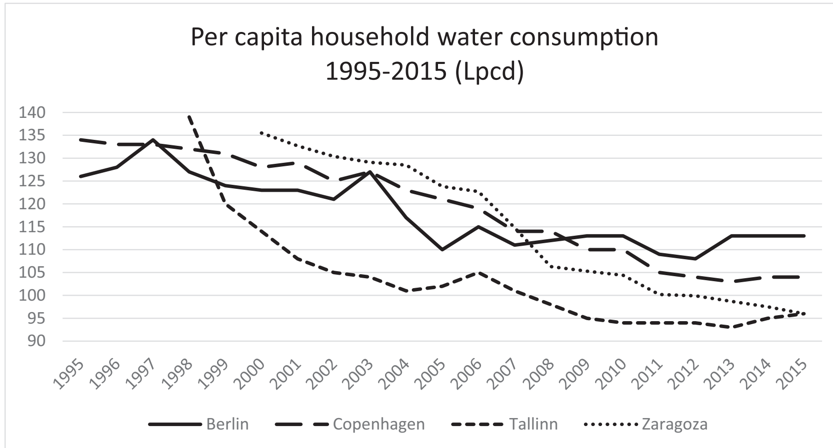

Fig. 1. Average household water consumption from 1995 to 2015 in Berlin, Copenhagen, Tallinn and Zaragoza (in Lpcd).

29% (Zaragoza since 2000) and 31% (Tallinn since 1998), respectively.

Water utility officials were asked to rate the impact of 13 individual WDM policies on reducing water consumption from 2005 to 2015 on a scale from 1 (lowest impact) to 5 (highest impact). The policy with the highest overall rating is investment in renovation and maintenance of networks, which three out of four cities considered high impact (defined as a rating of 4 or higher). The policy with the second-highest overall rating is campaigns promoting water-saving technologies, such as water-efficient appliances for toilets, showers etc. Four other policies share the third-highest overall rating: individual water meters; rapid leak detection mechanisms; public awareness campaigns; and municipal regulations. Each of these measures was rated as high impact in two cities. Finally, with slightly lower overall ratings, more efficient water use by industry and by the local administration were also considered high impact in two cities each. No city regarded higher average water prices to have had high impact; the same applies to legislation at the federal or regional level. The results are summarized in Table 2.

5.2. Impact in individual cities

Officials in Zaragoza rated nine policies as high impact, while six policies were considered high impact in Tallinn, five in Copenhagen, and none in Berlin.

Berlin has reduced water consumption by 10% without any WDM policy considered as high impact. Two policies were rated as medium impact (rating of 3): investments into network renovation and maintenance, and campaigns for the use of water-efficient technology.

Copenhagen is close to reaching its own residential target of 100 Lpcd. Domestic consumption reduced by 22% since 1995, and has almost halved within the last 30 years, from 192 Lpcd back in 1989 (Brears, 2017). Municipal regulations and initiatives are considered the most effective WDM policy to reduce water, followed by WDM policies focused on operational excellence (network renovation and maintenance, and rapid leak detection), and a more efficient water use by the local administration.

Tallinn is the city with the highest reduction of residential water use from 1995 to 2015. Considering consumption was estimated as high as 400 Lpcd in the early 1990s, the reduction – by roughly three quarters – seems even more remarkable (Lääne & Reisner, 2011). WDM policies with the highest perceived impact were operational (network maintenance and leak detection) and reducing water use in industry, followed by raising awareness (water meters and awareness campaigns), and greater control of illegal consumption.

Zaragoza is the city with the second-largest reduction of water use

Table 2
Impact of WDM policies on water conservation according to water utilities (from 1 – lowest to 5 – highest impact).

		Berlin	Copenhagen	Tallinn	Zaragoza	Sum
Tariff policies						
1	Higher average water price	1	2	2	3	*7*
2	Changes in tariff structure	1	1	1	**5**	*8*
Non-tariff policies						
Operation						
3	Investment in renovation and maintenance of networks	3	**4**	**5**	**5**	*17*
4	Installing mechanisms for rapid leak detection	2	**4**	**5**	2	*13*
Regulation						
5	Greater control of illegal consumption	1	1	**4**	**4**	*10*
6	Municipal regulations	1	**5**	2	**5**	*13*
7	Regional legislation	1	2	2	–	*5*
8	Federal legislation	2	1	2	–	*5*
Raising awareness						
9	Universal installation of individual water meters	1	3	**4**	**5**	*13*
10	Impact of awareness campaigns and public awareness for sustainable use of resources	1	3	**4**	**5**	*13*
Technological innovation						
11	Campaign for the use of water saving technologies (e.g. water-efficient appliances)	3	3	3	**5**	*14*
12	More control and more efficient use of water by the local administration	1	**4**	2	**4**	*11*
13	More efficient water use by industry[a]	1	2	**5**	**4**	*12*

Note: Policies that received an impact rating of 4 or 5 are highlighted in **bold**. The sum of all individual ratings across all cities is presented on the far right of the table. The closer the overall rating for a measure is to the theoretical maximum of 20 points, the higher its general perceived impact across all cities.

[a] While reduction in industrial water has no direct impact on residential water use, this additional data helps explain overall changing water use and consumption patterns in cities.

after Tallinn. It is also the city in which officials considered the highest number of individual WDM policies to have had a high impact; in fact, all policies – with the exception of rapid leak detection, regional and national legislation, and higher average water price – were considered to have had high or highest impact on reducing residential water consumption. Although the average price per cubic meter of water has increased in all cities since 1995, only in Zaragoza a change in tariff structures was regarded as high impact for water use reduction.

6. Analysis

The results show the wide variations of perceived impact from different WDM policies across all cities. In Berlin, for example, household water demand reduced considerably without any high-rated policy. BWB's main priority is to keep abundantly available water resources clean and reusable, not reducing water use. Awareness-raising policies focus on safeguarding water quality and preventing pollution. A brochure outlining “10 Golden Rules” for sustainable water use focuses on not disposing pharmaceuticals or other waste into the toilet, keeping water protection areas clean, and other measures minimizing pollution. Regarding water use, however, it states that adequate water resources are available, and one should not to save too much, as water quality is higher when it keeps flowing instead of stagnating in the pipelines (Berliner Wasserbetriebe, no date). A general high environmental awareness coupled with an overall sense of the importance of water among users seems to have led to more conscious (and lower) water use. However, this awareness has not been caused by individual household water meters: though BWB serves 3.5 million people, it only has 250,000 metered customers, as houses with several apartments usually share a single water meter.

Other policies Berlin has employed since reunification in 1990 have likely contributed to increased water conservation. After large investments in renovation and maintenance of water infrastructure, BWB's non-revenue water rate today stands at below 4%. Another important WDM policy might have been tariff reforms that took place in the early 1990s, specifically in East Berlin, and their long-term effects. The city reduced its water consumption by 40% between 1990 and 2010, due in part to a perceived “price shock” when tariffs were adjusted in East Berlin to West Berlin's levels, and in part to the decline of heavy (and water-intensive) industry. Income sensitivity of water demand in the new states in East Germany is still three times as high as in the old states in the West (Schleich & Hillenbrand, 2009). In 2015, however, tariffs were at a lower level than they were in the late 1990s (when correcting for inflation), yet with lower water use. Lower prices did not result in users consuming more water, but less.

In the following sections, the WDM policies with the highest-impact ratings are going to be assessed across the three other cities in the study: Copenhagen, Tallinn, and Zaragoza.

6.1. Tariff policies

Zaragoza is the only city that considered tariff reform to have had a high impact on water conservation. The City Council redesigned the water tariff explicitly to incentivize water saving in 2005, after evaluating findings from a long-term econometric study by the University of Zaragoza from 1996 to 2004. Arbués and Villanúa (2006) found that price sensitivity from 1996 to 1998 was inelastic, and did not incentivize water-conserving behavior; they recommended increasing current prices, and making these reflect marginal instead of average costs of water supply, to more accurately represent the value of water to users. The tariff was designed as a progressive block tariff, i.e. increasing prices per cubic meter of water for the first block up to 6 m^3; the second block up to 18.5 m^3; and the third block for any consumption above 18.5 m^3. By 2010, water prices (including wastewater treatment) reached between 0.43 EUR/m^3 for lower and up to 2.50 EUR/m^3 for higher usage levels (Celma, 2011). As an additional incentive, each household that reduced their water use by at least 40% within the first year of joining the new tariff would receive a discount of 10% on their water bill. These incentives seem to have been successful, given their uptake rates: from 2002 to 2006 alone, the number of households receiving this discount grew from 375 to almost 5000 (Kayaga & Smout, 2014).

Higher average water prices or tariff reforms were not mentioned as high-impact WDM policies in Copenhagen; however, their water prices are currently among the highest in Europe. Tariffs have increased from an average 3.60 EUR/m^3 in 1995 to 5 EUR/m^3 in 2015 (including wastewater treatment). The price is further expected to double within the next 10 to 15 years in order to finance investments into urban flood protection and other water-related climate change adaptation measures. Social media and other surveys by HOFOR show these investments enjoy public support. The utility has no block tariff system, as all household users pay the same price per cubic meter, regardless of their consumption; only large-scale industry users pay less.

Similarly, water utility officials in Tallinn did not consider tariff reforms or higher average prices as high-impact policies. However, officials interviewed at Estonia's Ministry of the Environment mentioned these as an important factor in decreasing water demand. Cost-recovery pricing for water supply and wastewater was introduced in Tallinn shortly after independence in 1991, mainly to generate funds for long-term water infrastructure construction and renovation. Over 20 years, the average price of water and wastewater treatment in Tallinn gradually increased by more than 800%, from 0.11 EUR/m^3 in 1995 to 0.95 EUR/m^3 in 2015, in a uniform tariff structure (no block tariffs). To ensure affordability, municipal regulations do not allow water tariffs to exceed 4% of disposable income; in Tallinn, the cost for water services is currently just about 1% of disposable income. However, tariffs can be considerably higher in less densely populated areas of Estonia, where economies of scale are weaker, and the average pipe length per customer is much higher than in the capital. National household water consumption is even lower than in Tallinn, at around 90 Lpcd (Global Water Partnership, 2017).

6.2. Non-tariff policies

6.2.1. Operation and regulation

In Copenhagen, great care is given to reduce leakage and water wastage during distribution. HOFOR has significantly reduced non-revenue water down to 7%, e.g. through its active leak detection program since 2012. It systematically checks the entire distribution network every 3 years, and employs noise loggers to detect leakage. In the interview, managers stressed how water loss reduction and continuously fixing any leaks are a high priority for the utility. Copenhagen's Water Supply Plan 2012–2016 has been developed between the municipality's Centre of Environment and HOFOR, as administration and utility cooperate to implement municipal regulations (Brears, 2017). Targets are set for security of supply, water quality and reducing imported water. Since the 1990s, water quality testing standards have been continuously updated, leading to shutting down several wells that had been polluted to a potentially hazardous level. Since 2010, water quality issues have largely driven water conservation, as further groundwater contamination would lead to closure of more wells that the city depends on. New forests have been planted to protect groundwater sources since 2002 (Brears, 2017).

In Tallinn – like in Estonia as a whole – physical water scarcity is not an issue for concern; yet ensuring water quality is. Thus, developing the sewerage system received more attention in the 1990s (Hanni, 1997). Tallinn, in its efforts to adhere to water quality requirements as specified in the European WFD, received long-term loans from the European Union to invest into its water infrastructure. In the process, leak detection and repair were significant improved. From 2002 to 2015, the percentage of leakages was reduced from 32% to 15% (Tallinna Vesi, 2017).

Zaragoza's water infrastructure also received large-scale investments, mainly to reduce leakage and water losses in distribution networks and in storage. From 2002 to 2009, investments into the sector totalled EUR 85 million, of which 65% were used to renovate the distribution network. As a result, total number of recorded pipeline leaks per year halved, from 664 in 1996 to 331 in 2008. Another EUR 37 million were invested from 2009 to 2013 to improve the sewerage system, water treatment facilities, flood prevention, and the creation of stormwater tanks (Celma, 2011).

In both Tallinn and Zaragoza, greater control of illegal water consumption was stated as a high-impact policy.

6.2.2. Raising awareness

All buildings in Copenhagen connected to the public water supply are required by law to have a water meter installed at property level, though not at the household level. HOFOR receives around 2 million DKK (ca. 260,000 EUR) yearly from the municipality to install individual water meters. HOFOR's research has shown that water savings of around 20% are made after installation (Brears, 2017).

In Tallinn, the installation of individual water meters started in 1995, and is considered one of the key policies reducing household water consumption. In 2000, the utility was mandated to install meters in order to bill for water fees. For blockhouses with several apartments, there is one meter measuring water use for which the respective housing association will need to pay. Each individual unit, however, will have a sub-meter measuring individual household consumption, which has to be paid to the housing association. After the introduction of water meters, a market for water-saving devices slowly emerged, enabling more companies to sell things like two-flush toilets, low-pressure shower heads etc. Water metering also incentivized repairing pipes and water leaks in the household. Public information campaigns on water focused mainly on tap water quality and safety – which improved significantly after independence in 1991 – and on water saving.

In Zaragoza, a long-term, multi-level water conservation program was established for residents, schools, public administration, small businesses and industry. The program was particularly effective in raising awareness about the scarcity and the value of water by engaging water users, in several consecutive phases (Philip, 2011).[1] The program worked well in creating awareness and initiating change in water users' consumption behavior. When the city posed a 1bn liter water saving challenge, population surpassed the goal set within the first year, saving 1.176bn liters, more than 5% of yearly domestic water (Kassam, 2014). Also, the program was accompanied by the universal installation of water meters in households, in order to provide direct feedback on water consumption in tandem with tariff changes.

6.2.3. Technological innovation

Another policy priority for Copenhagen is to make water use and distribution by the municipal administration more efficient. As almost all of the city's water has to be transported from outside municipal borders, HOFOR eases water demand peaks by pumping water into several large water tanks overnight. Thus, water demand spikes in the mornings and evenings can be addressed with less risk of bottlenecks.

In Tallinn, one of the overarching reasons for reducing overall water use was the industrial sector's transformation after 1991. Post-Soviet water volumes for industrial production decreased as more water-efficient production technologies were implemented. Some water-intensive industries in the area closed, like pulp and paper factories (Vinnari & Hukka, 2007). Also, a more effective modern wastewater treatment plant was built. However, next to industrial water savings, a significant amount of water conservation clearly took place in the residential sector as well.

In Zaragoza, new water-efficient technologies were integrated into its water-conservation program. New devices for less household water consumption were showcased in public places, including distributing information on water-saving measures. The city also promoted higher water efficiency in the industrial sector, and encouraged reducing the level of wastewater contamination from production processes, ensuring water sanitation tariffs were proportional to the amount of pollution from effluents (polluter-pays principle). The administration further made efforts to use water more efficiently itself, using more water-efficient plants in public gardens, and introducing intelligent irrigation systems to minimize water waste (Celma, 2011).

6.3. Discussion

All four cities share certain water challenges, and some respective policy responses. Copenhagen and Zaragoza both face risks of groundwater pollution, mainly due to intensive agriculture, and of water scarcity, due to their geography (Copenhagen) or their climate and resulting risks of drought (Zaragoza). Both cities set specific water conservation goals to reduce demand, and implemented a host of different WDM policies to incentivize users to save water.

In contrast, Berlin and Tallinn are not limited by a natural lack of water resources. Instead, the main threat to water security is contamination of potable water resources. But an opportunity for more efficient water use, technological innovation, and water savings presented itself after reunification (Berlin) and independence (Tallinn). Both cities have not set targets for reducing demand, but instead focused on limiting water pollution. However, with the implementation of demand management policies, residential water use decreased over time. While ensuring water quality and protecting potable water resources from pollution was the main priority, water conservation followed as water infrastructure was improved, more wastewater was treated, and cost-recovery tariffs were implemented.[2]

All four cities are required to implement the European WFD and its water quality requirements. All benefit from the common policy framework, its policy "toolbox" including cost recovery mechanisms and the polluter-pays principle, and EU funding opportunities. Tallinn and Zaragoza have taken advantage of available EU loans for necessary infrastructure investments. In fact, the most effective demand management policy across all cities is maintenance and renovation of water network infrastructure. This is a high-priority area for all cities (even in Berlin to a lesser extent), as substantial water and cost savings are possible by reducing non-revenue water. Another policy regarded as highly effective is raising awareness, i.e. the installation of universal water meters, and public information campaigns. Campaigns on water saving technologies (e.g. water-efficient appliances) and sustainable use of resources were also considered to have had a high impact, despite the literature being more cautious about their effectiveness (Inman &

[1] Phase 1, "Small steps, big solutions", started with a widespread awareness-raising campaign to conserve water in households, public buildings and businesses through behavioral change and implementing water efficient technology. Phase 2, "50 good practices", implemented and promoted 50 examples of water saving technology and practices in public parks, gardens, public buildings and the industrial sector, to showcase water saving effects and encourage uptake among city residents. In phase 3, "School for efficient water use", pocket guides were disseminated among the city's major water consuming sectors, detailing the good water saving practices identified in Phase 2. Finally, in Phase 4, citizens and businesses were invited to make "100,000 Commitments" to save water, and to present these commitments in time for the International Expo on Water and Sustainable Development which opened in Zaragoza in 2008.

[2] Berlin further reveals some of the potential downsides of reducing water consumption to unsustainable levels, in particular from the perspective of the water utility. First, from a technological perspective, the network infrastructure might prove oversized and inefficient. As a minimum water flow is needed in certain pipes to prevent stagnation, too low a flow increases technical, hygiene, and health risks. Reducing pipe diameter within the network to ensure acceptable water flow, on the other hand, is very expensive. Second, from a business perspective, lower water use leads to a decrease in revenue, and might impair the utility's capacity to finance necessary water network construction and maintenance. And finally, groundwater levels in Berlin have risen as a result of reduced extractions to levels where in some areas, high water tables prevent construction projects from going forward.

Jeffrey, 2006).

Tallinn and Zaragoza both have the largest number of policies perceived as high-impact, and both show the largest reductions in water consumption from 1995 to 2015 as well as the lowest per capita residential water use in the group. This seems to indicate that a larger number of effective policies lead to more successful water conservation results.

The perceived impact of specific policies might also relate to their time of implementation, i.e. how long ago they were introduced. In Berlin and Copenhagen, policies such as cost-recovery tariffs and the modernization of its water infrastructure were already being implemented since the late 1980s and early 1990s; Tallinn implemented new policies in the mid-1990s, and Zaragoza began its reforms in the mid-2000s. This might also offer an explanation specifically for the perceived low impact of tariff effectiveness in all cities but Zaragoza: perhaps the other cities are experiencing an "off-setting" effect regarding tariffs, as users have been accustomed to prices, adjusting their demand to previous levels (or somewhat higher) and no longer focusing on additional costs of their consumption. Prices could have lost their signaling function. Nevertheless, earlier tariff reforms seem to have played a role in reducing demand when introducing policies for the first time in East Berlin and in Tallinn, according to interviewees. Those additional revenues also enabled necessary renovation and maintenance of water infrastructure.

7. Conclusion

Household water use has significantly reduced in all four cities, and a variety of different WDM policies are credited to have had a high impact on water conservation over the last decade. These include: water network infrastructure investments and leakage control; water conservation campaigns and increased use of water-efficient appliances; the universal application of individual water meters; and municipal regulations. Since several of these policies reinforce each other – creating both awareness for water scarcity and incentives for conservation for users – a package of several inter-related policies seems to have brought best results, based on the perception of our interview partners and corroborating sources of information. In the study, the cities with a comparatively larger number of perceived high-impact policies also featured the lowest residential water consumption.

Different policy objectives may have led to reduced water consumption. Next to setting water conservation goals, a focus on improving water quality can result in significant and long-lasting water savings. However, while water conservation is often a strategic priority and a desired outcome, it can also put pressure on the water utility. If water consumption is too low relative to the size of the water network infrastructure, this may lead to additional technological, cost, health and hygiene risks. The European WFD helped by providing shared mandatory water quality targets, a flexible toolbox of WDM and other policies, and financial support. Its main objectives are water quality and environmental protection; however, since the problems of water scarcity, quality deterioration, and managing costs for water services and infrastructure needs are all interrelated, many WDM policies tackle several of these challenges at once, by safeguarding sustainable water protection and re-use.

As this study is limited by the primary data collected in the form of local water expert evaluations, further research on urban WDM strategies might take advantage of the increasing usage of smart water meters to address existing data limitations in household water use, for three reasons. First, the accuracy and availability of household water data will most likely increase. Second, data collection will be greatly simplified. And third, the ability of smart meters to identify and measure specific water uses (e.g. showering, washing machines etc.) will provide more precise and detailed data, providing valuable insights on how to fine-tune policies to more effectively target desired behavioral changes at the household level.

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