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Global diffusion of XL-capacity seawater desalination

Eran Feitelson[a] and Ariahna Jones[b]

[a] *Corresponding author. The Hebrew University of Jerusalem, Department of Geography, Mount Scopus, Jerusalem 91905, Israel. E-mail: msfeitel@mscc.huji.ac.il; efeitelson@gmail.com*

[b] *Shorelands and Environmental Assistance Program, Washington Department of Ecology, Olympia, WA, USA*

Abstract

In the wake of rapid population growth coupled with climate change and environmental degradation, countries around the world face increasing uncertainty in their ability to provide ample, safe and sustainable potable water. To meet this uncertainty, seawater desalination has been advanced around the world as a reliable new supply that improves water quality, aquifer restoration, water security and is essentially insensitive to climate change. Not only are the number of facilities increasing, but the size of the facilities is also increasing in order to take advantage of economies of scale. This paper analyzes the emerging trend of extra-large-capacity (XL) seawater desalination facilities by examining the rate of their global diffusion and the variables that influence this rate. These variables are explored quantitatively using logistic regression. In addition, selected country case studies provide insight into the factors that drive the adoption of XL desalination. They indicate that the decision to embark on XL desalination is largely determined by internal political factors. Specifically, XL desalination is advanced when the political costs of alternative water management strategies are high.

Keywords: Global diffusion; Politics; Seawater desalination

1. Introduction

As freshwater supplies dwindle, an increasing number of countries look towards the sea as an alternative source for potable water supply through desalination (Lopez-Gunn & Llamas, 2008). Due to its high cost and energy demand, desalination has historically been unattainable aside from the energy-rich and water-poor countries around the Arabian Gulf. This exclusivity has recently changed as technological advancements have reduced the cost of desalination (Khawaji *et al.*, 2008; Bernat *et al.*, 2010) at the same time as the cost and unreliability of traditional freshwater supplies have increased (Falkenmark & Molden, 2008; Schiermeier, 2008; Wade *et al.*, 2013). However, the role and importance of seawater desalination to meet future water demands are unclear and contested. Although seawater desalination may be necessary to overcome water shortages in many arid areas, several analysts argue that science

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and technology by themselves are not sufficient to solve the growing global water problems (Schiffler, 2004). Moreover, desalination may draw attention away from less costly and more environmentally sound alternatives such as water conservation, water-use efficiency and water recycling (Meerganz von Medeazza, 2004; Cooley *et al*., 2006; Dickie, 2007). The emerging consensus seems to be that the use of desalination has the potential to be a critical component in balancing a region's water budget, but it should nevertheless be implemented as a last resort, only pursued after all other demand management[1] and water reuse options have been exhausted (Schiffler, 2004; Lattemann & Höpner, 2008).

Regardless of the perspective on seawater desalination, rapid global diffusion is apparent with over 100 countries around the world utilizing the technology to overcome chronic water shortages (Media Analytics Ltd (MAL), 2013). There have been an increasing number of studies directly and indirectly related to the regional diffusion of desalination (Cooley *et al*., 2006; El Saliby *et al*., 2009; Palomar & Losada, 2010; Sowers *et al*., 2011), and to a lesser extent the global diffusion of seawater desalination (Dickie, 2007; Bernat *et al*., 2010). However, none of these studies have focused on the diffusion of extra-large-scale[2] (XL) seawater desalination. Over the past decade the size of seawater desalination facilities has been increasing in order to take advantage of economies of scale. These facilities are not only providing a 'new' freshwater resource,[3] but they are also producing potable water in large quantities that go beyond augmenting supply for local shortages by providing a base-flow for growing populations (Feitelson & Rosenthal, 2012).

As the 'business as usual' routine for water management is changing rapidly due to critical water scarcity situations around the world and technological advancements to address them (Lopez-Gunn & Llamas, 2008), it is important to take a fresh look at current developments in XL seawater desalination. This paper addresses the topic by asking three fundamental questions: What is the rate at which XL seawater desalination is being adopted? What variables affect this rate? And, in particular, how do socio-economic-political factors affect the diffusion? These questions are analyzed both quantitatively and qualitatively. The paper is structured in the following way: First, a snapshot of the current (end of 2012) status of desalination is presented, showing that XL desalination provides almost two-thirds of the desalination capacity, and its share is growing – hence, the emphasis on XL plants in this paper. Then, the factors that drive or obstruct the diffusion adoption of XL desalination are spelled out on the basis of the literature. Next, a quantitative analysis using logistic regression is used to assess the influence of these factors on the adoption of XL seawater desalination. As the results do not prove to be conclusive, several country case studies are presented to gain insights into the political and socio-economic factors that affect the rate at which XL seawater desalination plants are adopted. To conclude, findings from the quantitative and qualitative analyses are discussed in terms of the current observed status of the global diffusion of XL seawater desalination, as well as the importance of this topic for water managers and future research.

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[1] In demand management we also include the substitution of fresh water by virtual water, which allows fresh water to be shifted from irrigation to domestic use.

[2] Based on Lattemann (2010) desalination capacity is categorized as follows: XL $\geq$ 50,000 m^3/day $>$ $L \geq$ 10,000 m^3/day $>$ $M \geq$ 1,000 m^3/day $>$ S.

[3] 'New' freshwater resources refers to additional volumes that can be introduced to the hydrological cycle such as desalination, wastewater reuse or bulk importation (Lopez-Gunn & Llamas, 2008).

2. Desalination today: a cross-sectional global snapshot

The desalination industry is seeing unprecedented growth and diffusion around the world as countries struggle to maintain a positive water balance. However, due to the rapid pace of development, global extent, local issues and nature of private contracts for desalination facilities, it is difficult to pinpoint and follow the precise worldwide status of desalination. Media Analytics Ltd (MAL) has been at the forefront in collecting and organizing desalination data through their magazine Global Water Intelligence (GWI) and website DesalData.com. The company has also partnered with the International Desalination Association (IDA) in creating the annual IDA Yearbook, which serves as a comprehensive guide to the year's desalination market. The data from the IDA Desalting Plants Inventory on the website DesalData.com currently provide the most extensive global list of desalination facilities. For this reason, the inventory as of January 2013 is the primary source of information for this paper. The following sections are based on the analysis and interpretation of the inventory.

The total production capacity of all seawater desalination plants worldwide that are online or presumed online is approximately 37.7 million cubic meters per day (Mm^3/day). Another 10.5 Mm^3/day will be added by plants currently (January 2013) under construction. In total, there are 4,639 seawater desalination plants worldwide with an overall capacity of 48.1 Mm^3/day that are either under construction, online or presumed online. As seen in Figure 1(a), this number accounts for 36% of all desalination plants (including all source water types).[4] However, among desalination plants with larger capacities, the percentage of seawater facilities accounts for 47% of large plants (with a capacity greater than or equal to 10,000 m^3/day) and 74% of XL plants (with a capacity greater than or equal to 50,000 m^3/day); see Appendix, available online at http://www.iwaponline.com/wp/016/066.pdf.

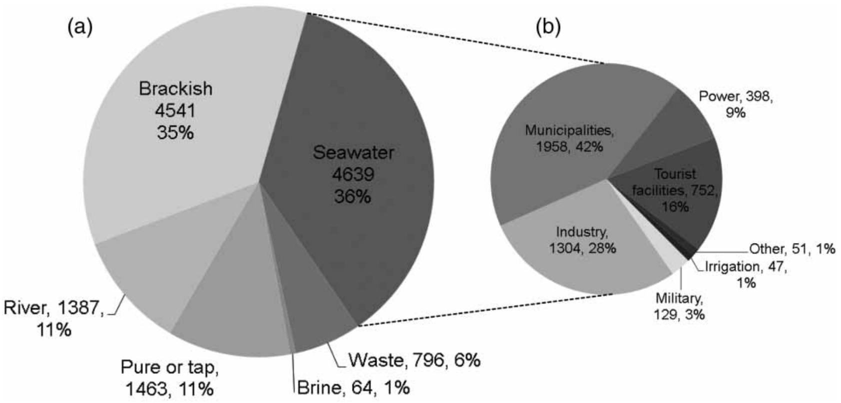

Fig. 1. (a) (Left) Snapshot of the desalination industry showing number of plants by water source type. Figure includes plants that are under construction, online and presumed online. *Primary source*: MAL (2013). (b) (Right) Snapshot of the global market for seawater desalination showing number of plants by user category. Figure includes plants that are under construction, online and presumed online. *Primary source*: MAL (2013).

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[4] All source water types include brackish water, river water, wastewater, brine and pure or tap water, in addition to seawater, in the IDA Desalting Inventory.

2.1. Use of seawater desalination

Desalination technology is being utilized for a range of end-users including municipalities, industry, the military, power stations, irrigation and the tourism sector. Due to the quality requirements of domestic needs (which limit the potential sources for desalination), the major end-user for seawater desalination is municipalities (see Figure 1(b)). Among XL seawater desalination, the dominance of municipalities in the market is even clearer as their share jumps from 42 to 80% (MAL, 2013).

2.2. Technology

Thermal processes such as multi-effect distillation and multi-stage flash (MSF) laid the groundwork for modern desalination. However, in the past 20 years most of the plants built use membrane processes such as electrodialysis and reverse osmosis (RO) (MAL, 2013). While MSF is viewed as the most robust desalination technology and is valued for its ability to produce significant amounts of high-quality water, its high energy intensity has limited its utilization to oil-rich countries around the Arabian Gulf (Bernat *et al.*, 2010). Membrane technologies such as RO are not only less energy-intensive, but they also hold possibilities for the removal of other contaminants (bacteria, organic matter, viruses, etc.) and are thus increasingly attractive to supply potable water to meet the quantity and quality demands for municipal supply (Elimelech & Phillip, 2011).

2.3. XL seawater desalination

Worldwide, there are currently 203 seawater desalination plants that are under construction, online or presumed online that have an XL capacity of greater than or equal to 50,000 cubic meters per day (m^3/day). These account for only 4% of the total seawater desalination plants globally. But in terms of capacity, XL facilities will produce 32.1 Mm^3/day accounting for 67% of the global desalination total capacity. Of the 152 XL seawater desalination plants operating at the beginning of 2013, 107 (70.4%) have come online since 2000. If the 51 plants under construction are added to the total number of plants that have come online in the last 4 years, then 66.5% of the 203 plants are post-2008.

The majority of XL seawater desalination plants are currently still concentrated in the Arabian Gulf countries (Figure 2). However, the relative share of the Gulf countries is decreasing. While Gulf countries held 94% of the desalination market before 2000, by the end of 2005 seven new countries contracted XL seawater desalination plants and the Gulf's share dropped to 78%,[5] dropping further to the 57% seen in Figure 2 for 2013. As of January 2013, 29 countries have XL seawater desalination facilities and an additional nine countries are in the planning stages.[6] In Figure 3 the countries that had XL desalination plants in August 2011 are depicted against the background of the total renewable water, showing the concentration of XL desalination in the water-scarce Gulf countries, the Mediterranean region and island states.

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[5] These figures represent all XL seawater desalination plants that were contracted during the mentioned time periods and thus include plants that are currently offline or presumed offline.

[6] Countries without, but planning future, XL-capacity seawater desalination (number of plants planned): Ecuador (1), Egypt (1), Jordan (1), Mexico (2), Pakistan (3), Peru (1), Philippines (3), South Africa (2) and Tunisia (3). A detailed list of countries with XL plants can be found in the Appendix, available online at http://www.iwaponline.com/wp/016/066.pdf.

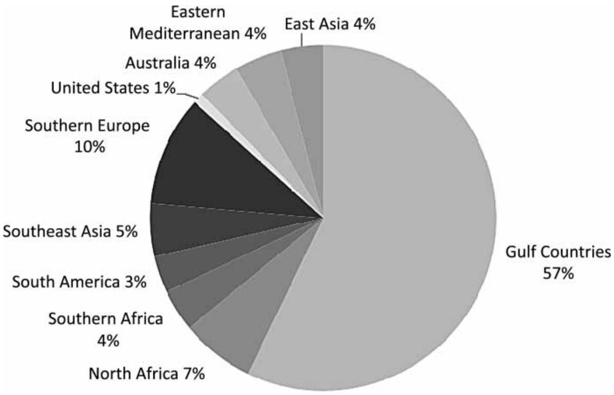

Fig. 2. Percentage of XL seawater desalination plants by region. See Figure 4 for regional breakdown of countries. Figure includes plants that are under construction, online and presumed online. *Primary source*: MAL (2013).

3. The diffusion of XL desalination: an overview

In technology diffusion theory, the adoption curve is typically S-shaped (Hall, 2004). Worldwide, countries can be found at almost every stage in the adoption curve of XL desalination, ranging from countries that already heavily rely upon seawater desalination whose market is becoming saturated to those that are just beginning to consider it with an expanding market.

It is apparent from Figure 4 that the trend in the diffusion of XL seawater desalination is not only on the increase, but it has also been extremely rapid in the last decade. Furthermore, the population of adopters is widening as countries around the world begin to consider implementing XL seawater desalination in order to counter prolonged water deficits. However, the world economic downturn since 2008 has somewhat slowed down this trend, as the number of contracted plants declined after an all-time high in 2007.

3.1. Driving factors

Several factors can be hypothesized as driving the rapid diffusion of XL desalination in recent years. The first is the increasing awareness of impending water scarcity as the number of basins being closed rises (Falkenmark & Molden, 2008; Molle, 2008). These concerns over impending scarcity are heightened by forecasts of the deleterious effects of climate change on water availability, particularly in the semi-arid water-scarce parts of the world (Schiermeier, 2008; Sowers *et al.*, 2011; Haddeland *et al.*, 2014). A second factor favoring seawater desalination arises from the changes in population dynamics. While migration and urbanization create pressures on freshwater resources through pollution and increased demand (National Research Council (NRC), 2008), approximately half the world's population live within 200 kilometers of a coastline and by 2025 that figure is likely to double (Creel, 2003). This population is becoming increasingly urbanized with 18 of the world's 27 mega-cities (populations ≥ 10 million) located in coastal areas. These mega-cities are projected to face some of the largest population pressures (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2008; World Water Development Report 3 (WWDR3), 2009), and hence potable water supply challenges.

The third factor inducing the rapid diffusion of XL desalination is its increasing affordability. In the past 10 years the price of desalination has substantially decreased due to technological advancements in

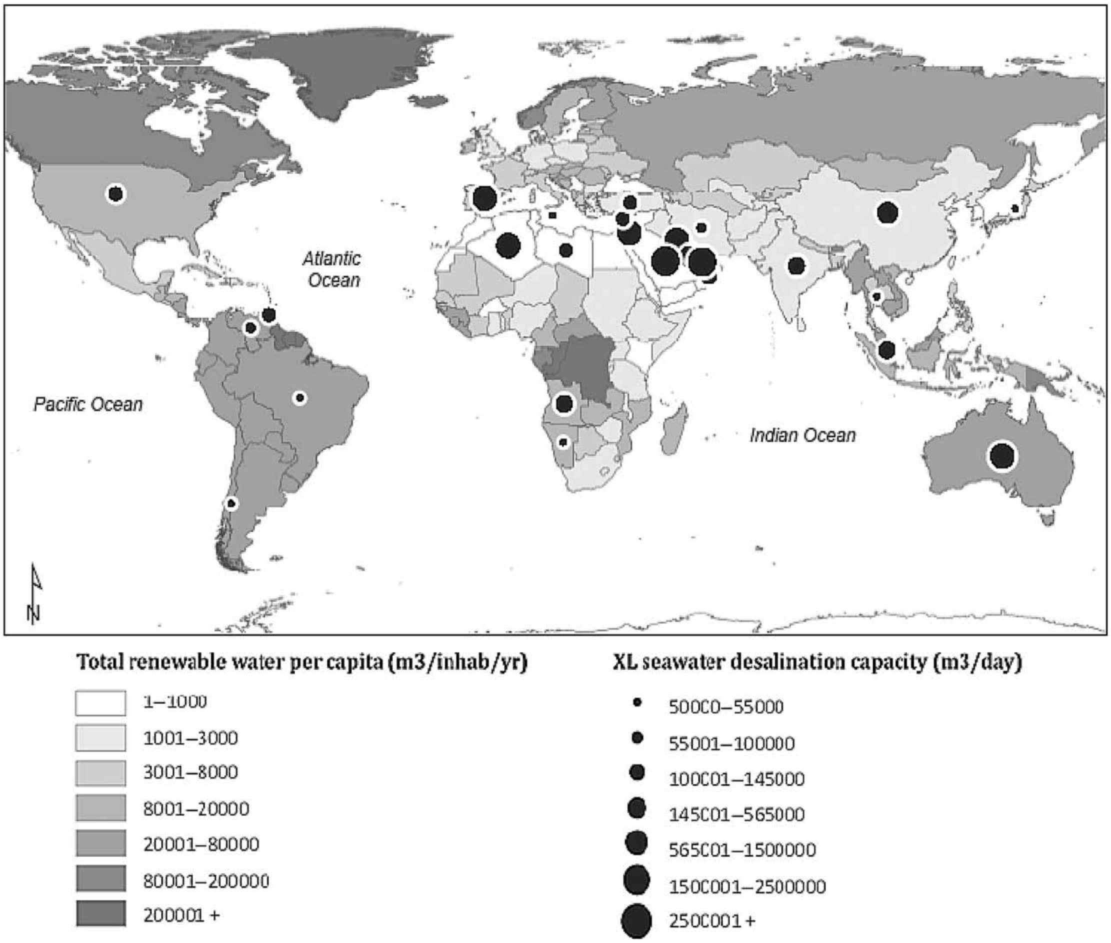

Fig. 3. XL seawater desalination capacity in 2011 by country. Figure includes plants that are under construction, online and presumed online. *Primary source*: MAL (2011). *Note:* Capacity circles do not represent location of facilities. Countries (in decreasing order): Saudi Arabia, United Arab Emirates, Spain, Kuwait, Algeria, Australia, Israel, Qatar, Oman, Bahrain, Singapore, China, India, Angola, Iran, Trinidad & Tobago, Chile, Cyprus, USA, Libya, Thailand, Morocco, Venezuela, Ghana, Japan, Namibia, Brazil, South Korea, Malta.

membranes and energy recovery systems (McGinnis & Elimelech, 2008; Bernat *et al*., 2010). According to recent reports, the operating costs of desalinated water have fallen over the last 20 years from an average of US\$1.25–1.50 per m^3 in the early 1990s to an average of less than US\$0.75 per m^3 today (Bennett, 2011). This is partially due to companies taking advantage of economies of scale, with the cost of desalinating seawater substantially reduced as the capacity of the plant increases[7] (Bernat

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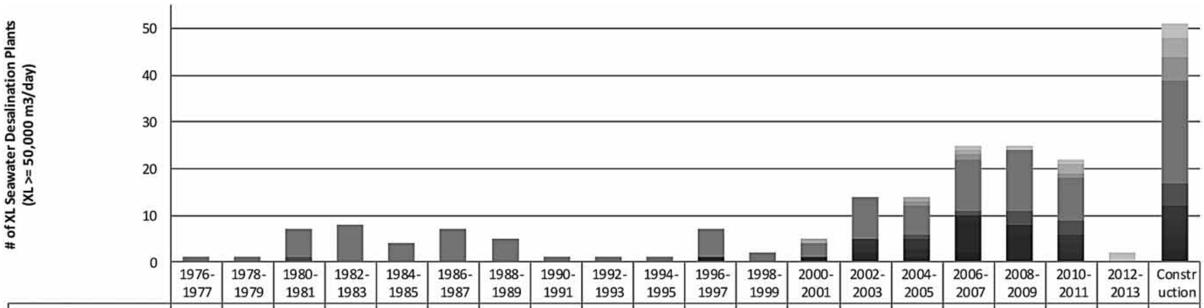
[7] Seawater desalination plants with a capacity less than 1,000 m^3/day have an average cost of US\$2.40–12.30 per m^3 whereas XL seawater plants with a capacity greater than or equal to 50,000 m^3/day have an average cost of US\$0.45–1.10 per m^3 (Bernat *et al*., 2010).



	1976-1977	1978-1979	1980-1981	1982-1983	1984-1985	1986-1987	1988-1989	1990-1991	1992-1993	1994-1995	1996-1997	1998-1999	2000-2001	2002-2003	2004-2005	2006-2007	2008-2009	2010-2011	2012-2013	Construction
▨ Australia																1	1	1	2	3
▨ Eastern Mediterranean													1		1	1		2	0	4
▨ East Asia															1	1		1	0	5
▨ Gulf Countries	1	1	6	8	4	7	5	1	1	1	6	2	3	9	6	11	13	9	0	22
■ North Africa			1												1	1	3	3	0	5
■ Southern Africa														1	2			2	0	3
■ South America														2				2	0	3
■ Southeast Asia															2	1	2	2	0	3
■ Southern Europe											1		1	2	1	7	6	0	0	3
■ United States																2		0	0	0

Fig. 4. XL seawater desalination plants online dates by region. *Primary source*: MAL (2013). Eastern Mediterranean: Israel & Cyprus. East Asia: China, Japan, South Korea. Gulf Countries: Bahrain, Iran, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates. North Africa: Algeria, Libya, Morocco. Southern Africa: Namibia, Angola, Ghana. South America: Brazil, Chile, Venezuela, Trinidad & Tobago. Southeast Asia: India, Thailand, Singapore. Southern Europe: Spain & Malta.

et al., 2010). This trend, coupled with the increasing cost of traditional water supplies in treatment and conveyance, makes seawater desalination increasingly attractive to countries around the world that face chronic water shortages. However, it should be noted that because the cost estimates rely on a variety of factors such as method, source water, energy source, and other environmental needs, overall cost comparisons between specific sites can be misleading.[8] Concurrently, the gross domestic product (GDP) per capita of middle-income formerly developing countries has risen substantially, allowing a widening set of countries to undertake large-scale desalination.

3.2. Challenges and barriers to desalination diffusion

There are, however, several factors that may impede the diffusion of desalination. These include the high cost, disposal of brine, greenhouse gas (GHG) emissions and reliance on non-renewable energy sources (Carter, 2013). These latter three factors are the main negative externalities associated with desalination (Elimelech & Phillip, 2011). Additional, indirect, challenges involve the social impact on the surrounding community through fisheries, land use and population growth (Meerganz von Medeazza, 2005). In terms of specific challenges associated with XL seawater desalination, the major concerns involve energy, environmental impact and land use.

Water and energy have always been intimately linked as the production and conveyance of water usually require significant energy, and energy production often requires significant quantities of

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[8] Many people have attempted to classify the costs in order to have more meaningful comparisons (Karagiannis & Soldatos, 2008; UNESCO, 2008; Wittholz *et al.*, 2008), but others still warn that ultimately the actual cost of desalination cannot be predicted (Cooley *et al.*, 2006).

water, thereby creating the water-energy nexus (Bennett, 2011). As the majority of large-scale desalination plants are fossil-fuel driven, opponents of large-scale desalination point out that it actually shifts the natural resource problems from water scarcity to non-renewable energy (Meerganz von Medeazza, 2005). However, recent technological advancements in energy recovery systems have reduced the amount of energy needed, and the current generation of seawater RO desalination plants consume between 3 and 4 kilowatt hours per cubic meter (kWh/m^3), which is approximately 20% of the energy used in the first generation of RO desalination plants (Elimelech & Phillip, 2011). In addition, significant R&D efforts towards the use of alternative and renewable energy sources in desalination are being pursued but are currently limited to smaller less energy-intensive facilities (UNESCO, 2008).

Seawater desalination facilities raise several environmental concerns that must be assessed and mitigated. These include the immediate ramifications of the construction and land use[9] as well as the long-term operational effects of the plant with regard to the intake of source water and disposal of brine concentrate (Lattemann & Höpner, 2008; Lattemann, 2010; Cooley *et al.*, 2013). However, a widely accepted view in the literature on current seawater desalination facilities is that these environmental impacts will not be substantial if appropriate measures are taken (Elimelech & Phillip, 2011). These include use of novel materials that help improve efficiency and hence reduce energy use and GHG emissions, low-velocity intakes and screens that reduce impingement of large organisms, and dilution of brine with other streams (such as cooling water from power stations)[10] and careful siting of intake and outflow pipes.

A third major concern surrounding XL seawater desalination is its potential to promote population growth in coastal areas (Cooley *et al.*, 2006). With the forecasts for sea-level rise, any factor promoting such an increase can be seen as problematic. But the extent to which XL desalination will affect population growth has not been analyzed rigorously.

3.3. Driving and obstructing factors: an overview

The discussion so far has identified several factors that seem to drive the diffusion of XL desalination and a few that may obstruct it. The questions that now arise are when and where are the driving forces overcoming the obstructions, and how do these balances of forces shift over time and space.

It can be hypothesized that the most important factors driving XL desalination are the increasing pressures on water resources, driven by population growth and rising GDP per capita (which increases domestic water use per capita in low- and mid-income countries).[11] The second set of factors is the rapid increase of GDP in the emerging economies, particularly China, south-east Asia, India and Latin America, which increases their capacity to pay for desalination. Consequently, when combined with the decrease in desalination's pecuniary cost, desalination can be expected to become increasingly affordable to a widening set of countries.

In contrast to the clear shift in driving forces, the directions for obstructive factors are less clear. While the awareness of the potential drawbacks of desalination seems to be rising (e.g. Meerganz

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[9] The land required for desalination facilities does not only include the facility site, but also includes the land needed for conveyance infrastructure and the coastal area needed for water intake and discharge.

[10] Cooling water can serve also for intake, thereby reducing the potential effect on marine biota.

[11] Desalinated seawater from XL plants is largely used for supplying domestic demand, and the main potential for further expansion of XL plants is in mid- and low-income countries, where population growth is high.

von Medeazza, 2005; Cooley *et al*., 2006; Dickie, 2007), technological improvements are being made to address these concerns (Elimelech & Phillip, 2011).

Hence, when considering all factors in tandem, it seems that the main factors that drive the diffusion of XL desalination are GDP per capita (as it affects both the domestic demand for water and affordability), population growth and migration (particularly the growth of urban population near the coast), and the rate of technological improvements.

4. The diffusion of XL seawater desalination: a quantitative analysis

In order to test the hypotheses raised in the previous section, a logistic regression analysis was undertaken.

4.1. Methodology

The operational explanatory variables used in the regression and the sources of data for each are listed in Table 1, as well as the limitations of each variable. These include the GDP per capita, R&D expenditures as a proxy for technological change, the water stress as accounted for by the renewable water per capita, the total water withdrawal per capita and dam capacity (assessing inter-annual storage capacity). In addition, the variables used include population growth, urbanization and population density as factors inducing domestic demand for water.

Data were collated regarding these variables for 110 countries that currently have seawater desalination (and hence have the potential to adopt XL plants), and for whom data were available.[12] Then, a separate binary variable was created in which the 29 countries that have XL seawater desalination facilities were assigned a value of 1 and the rest a value of 0. A Pearson's correlation was performed to assess the influence of the eight independent variables on the created dependent variable of whether or not the country currently has XL seawater desalination plants. As can be seen in Table 2, three variables showed a significant correlation at the 0.05 level (in a two-tailed significant test). These variables, 'population density', 'population growth', and 'GDP per capita', were all selected for further analysis through binary logistic regression.

The binary logistic regression function in the statistical package SPSS 19.0 was used to test the basic null hypothesis that the chosen variables do not have any influence on the dependent dichotomous variable of having XL seawater desalination. To test the overall fit of the model at 95% confidence, the Hosmer and Lemeshow chi-square test of goodness-of-fit was used. As the *P*-value derived is non-significant at the 0.05 level, the null hypothesis of no effect is not rejected, implying that the model fit is acceptable.

4.2. Results

The results of the regression are presented in Table 3. The correlation indicated that the variables related to affordability and domestic water demand, such as 'GDP per capita' and 'population density'

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[12] Overseas territories and administrative regions that were not listed in the databases used, or did not have data available for the selected independent variables, were not included in the study.

Table 1. Conceptual and implemented variables of interest in the diffusion of XL seawater desalination.

Conceptual variable	Operational variable of influence	Data source*	Limitations to study
Economic	• GDP per capita (current $US)	World Bank: World Development Indicators (WDI) – 'Economic Policy'	• Does not account for income distribution, which may affect household affordability
Technology	• R&D expenditure (% of GDP)	World Bank WDI – 'Science & Technology'	• Technology can be imported
Water stress	• Total renewable water resources per capita (m^3/inhab/yr) • Total water withdrawal[1] per capita (m^3/inhab/yr) • Dam capacity[3] per capita (m^3/inhab)	FAO[2] AQUASTAT Database	• Does not account for intra-country variances, which can be very substantial
Demand	• Population growth (annual %) • Urban population growth (annual %) • Population density(people per sq. km of land area)	World Bank WDI – 'Health & Urban development'	

[1] Total water withdrawal includes both surface water and groundwater withdrawals of all sectors.

[2] FAO: Food and Agriculture Organization of the United Nations.

[3] Total capacity of dams indicates the sum of the theoretical initial capacities of all dams within the country. Note: The amount of water stored within any dam is likely less than the capacity due to factors such as silting.

**Sources:* WDI and FAO AQUASTAT obtained January 2013 from http://databank.worldbank.org and http://www.fao.org/nr/water/aquastat/data.

Table 2. Results of Pearson's correlation test for XL seawater desalination.

Variable	Pearson's correlation	Significance
Population density	0.202*	0.034
Population growth	0.223*	0.019
Urban population growth	0.172	0.072
GDP per capita	0.225*	0.018
Research & development expenditures	0.187	0.097
Total renewable water resources per capita	– 0.142	0.148
Total dam capacity per capita	– 0.059	0.563
Total water withdrawal per capita	0.019	0.842

*Significant at the 0.05 level.

and 'population growth', play a role in the adoption of XL seawater desalination. In the logistic regression model, 'GDP per capita' and 'population growth' are both close to significance at the 0.05 level. This finding suggests that growth places pressure on governing officials to create a balanced and adequate water supply portfolio. Hence, population growth and economic affordability, rather than the existing water and settlement situation (measured by population density, water stress or dam capacity), are the main drivers of XL seawater desalination.

Table 3. Binary logistic regression analysis of socio-economic predictors of XL seawater desalination.

Variable	*B*	(95% CI)	*P*
Population density (people per sq. km of land area)	0.001	(0.999–1.003)	0.172
Population growth (annual %)	0.451	(0.999–2.465)	0.050
GDP per capita (current $US)	0.002	(1.000–1.004)	0.051

However, as the significance is low, it seems that the introduction or expansion of XL seawater desalination is highly variable, implying that local and state governments view this technology largely as an available option. But its adoption is a function of additional variables. As the cost of desalination is substantial, governments may first need to be reasonably confident that its associated costs are feasible, and then to convince constituents that their confidence in the cost-effectiveness of XL seawater desalination is not misplaced. Hence, a more detailed analysis of the factors that lead governments to build XL desalination plants is called for.

5. Trends in the diffusion of XL seawater desalination: a closer look at country case studies

While population pressures and GDP per capita affect the diffusion of XL desalination, they cannot explain why XL desalination is undertaken in specific locales. In order to gain insights into this question, we review a number of cases where XL desalination was implemented.

Clearly it is infeasible to conduct a large number of in-depth case studies within the scope of a single paper. Thus, in order to provide a wide picture, seven cases were reviewed on the basis of the literature. These cases are presented in relation to the diffusion curve of adoption. After a very brief review of the 'pioneering' countries from the Gulf, the seven cases from selected 'emerging' and 'incipient' countries are reviewed. Emerging countries were defined as countries where XL seawater desalination has become a significant source, at least for some metropolitan areas, entailing the construction of several XL facilities. Incipient countries are countries where at least one XL desalination plant was built, but where desalination does not yet play a major role in water supply. The emphasis on emerging and incipient countries is due to their being indicative of things to come, while the Gulf states increasingly seem to be an exception from a global perspective.

5.1. Pioneering countries

The pioneering countries of the Arabian Gulf not only helped to instigate the full utilization of seawater desalination, but they also remain leaders in the market to this day. The countries included in this group are the following: Oman, UAE, Qatar, Bahrain, Saudi Arabia, Kuwait and Iran. The aforementioned countries all began desalination due to two main factors: a lack of surface water and groundwater with a growing water deficit, and an abundance of financial and energy resources to undertake intensive supply-side solutions (Lattemann, 2010). The combination of these countries produces an impressive XL seawater desalination capacity of nearly 20.9 Mm^3/day (89% used for municipalities) (MAL, 2013). The diffusion of XL seawater desalination in the Arabian Gulf has seen two surges in production, but the overall trend is increasing. However, the lack of alternative water sources, coupled with the ample energy resources, allows them to use different technologies from those advanced elsewhere. It is doubtful, therefore, whether the considerations that drive desalination in this region are indicative of those that drive desalination elsewhere.

5.2. Emerging countries

The diffusion of XL seawater desalination plants for countries outside the Arabian Gulf has largely taken place within the last 10 years. Libya, Spain, Chile, Cyprus, and Trinidad and Tobago are the exceptions, having had online facilities prior to 2003. The countries that have begun to adopt or develop seawater desalination in the past decade exhibit more involved driving factors than the Gulf States as they have a wider opportunity set to address their emerging water stress. Five countries in this category are hereby reviewed: Spain, Algeria, Australia, USA and Israel. These cases are summarized in Table 4, according to the catalysts for adoption of XL desalination, the funding mechanism and the interests that support or oppose XL desalination.

5.2.1. Spain. Spain has been a catalyst for the emerging countries in pursuing desalination as a key component of their water portfolio. Currently Spain has 375 seawater desalination facilities with a total capacity of approximately 3.6 Mm^3/day (MAL, 2013). Outside of the Arab Gulf countries, Spain has the highest number of XL seawater desalination plants in the world with 17 online, and 3 under construction. Spain initiated desalination in Europe with their first plant beginning production in 1964 on the island of Lanzarote in the Canary Islands (Palomar & Losada, 2010). Although desalination began as a provider for tourism on the Canary Islands, it has since spread to the mainland, mainly to the south-eastern coast of the Mediterranean, which is the driest part of mainland Spain. In the last few years water shortage problems in this region have been aggravated by rapid development in the region's agricultural and tourism industries, and hence desalination is seen as a critical element in the region's water management plans (Downward & Taylor, 2007). However, today 88% of the seawater desalination capacity in Spain is used for municipalities (MAL, 2013).

Table 4. The factors driving desalination in emerging country case studies and their financing.

Country	Catalyst	Funding	Supporting and opposing actors
Spain	Opposition to the Ebro diversion	Public-private partnership	Wide coalition of supporters: economic, environmental and Catalonians. Part of national decentralization and marketization of water
Algeria	Desire to check rapid urbanization	Public-private partnership	Government-led
Australia	Major drought	Public-private partnership	Municipalities that seek climate proofing; opposed by environmentalists and World Bank; critiqued today due to excess capacity
USA	Local and state concerns about supply in drought situations	Public-private partnership	Environmental opposition due to effects on marine life and high energy consumption and resulting GHG emissions
Israel	Extended droughts; shift in attitude of treasury	Public-private partnership	Originally opposed by treasury; treasury changed disposition to promote PPP in water sector as part of neo-liberalization of the economy; wide coalition supports – farmers and environmentalists

Spain's history of water management shows an emphasis on expanding supply (Swyngedouw, 1999), which has in turn skewed the perception of available water. Many argue that this has allowed for negligent land-use planning and unregulated water extractions (Dickie, 2007). The national hydrological plan for Spain was previously focused on a project to transfer large quantities of water from the Ebro River through a 900 km-long aqueduct southward to more water-scarce regions (Saurí & del Moral, 2001; Meerganz von Medeazza, 2005). However, this plan was opposed by many Catalonians, as well as by environmentalists, and faced criticisms also by the European Union (EU) as it is seen to contradict the EU's water framework (Lopez-Gunn, 2009). Large-scale desalination was therefore advanced as an alternative to this plan in 2004, when the AGUA program was ratified, after a new government was formed (Garcia-Rubio & Guardiola, 2012). This program proposed that 34 desalination plants with a capacity of 600 Mm^3 would be built by 2008 as an alternative to the Ebro transfer plan (Lopez-Gunn & Llamas 2008).[13] One of the major factors in this decision was the protection of the Ebro River delta, a zone protected under Spanish and international environmental laws (Embid, 2003).

Although desalination requires large infrastructure and raises concerns for land-use planning, it is seen today as a preferred alternative in Spain in both economic and environmental terms as opposed to large dams and inter-basin water transfers (Palomar & Losada, 2010). Garcia-Rubio & Guardiola (2012) attribute this preference to the implementation of better technologies, resulting in reduced pecuniary cost, as well as improved capability to address the environmental externalities of desalination. However, the most important factor they note is strong political support for desalination. This support perhaps can be attributed to the conformance of desalination to the emerging federalism in Spanish water policies, whereby regional sovereignty over water is increasingly claimed (Lopez-Gunn, 2009). Swyngedouw (2013) goes further and attributes this widespread support to the complex network of actors and mobilization processes that have made desalination the central element in decentralization of water supply and the marketization of such supply.

5.2.2. Algeria. Initially utilizing desalination technology for industry in the 1960s, Algeria is now exploiting the technology to overcome their current water shortage and satisfy domestic demands (Sadi, 2004; Mitche *et al*., 2010). A new desalination program launched by the government has undertaken the construction of 16 XL desalination plants, making the country one of the world's fastest growing markets (Drouiche *et al*., 2011). In the last decade, eight XL seawater desalination plants have come online with construction begun on three others. Ten of the XL plants are based on RO technology, and all are designated for municipal use (MAL, 2013).

According to the Ministry of Water Resources, the main objective of the desalination program is to free water from the reservoirs so that it can be pumped up for irrigation in the High Plains zone, thereby slowing migration from the High Plains to the already crowded coastal plain where 80% of the population live (Mahmoudi *et al*., 2009). Desalination is thus part of a socio-political program geared to slow the volatile urbanization process.

The desalination program is conducted through a public-private partnership. The vast majority of the newly launched plants are under private build, own, and operate contracts (Mahmoudi *et al*., 2009). This allows the local governments to overcome the barriers of cost and uncertainty in the diffusion of seawater desalination as the private companies maintain the majority of the responsibility.

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[13] In practice only 214 Mm^3 of the proposed 600 Mm^3 were developed by 2008 (Lopez-Gunn, 2009).

5.2.3. Australia. Australia has faced an increase in duration and intensity of recent droughts and, in response, its major cities have sought to diversify their water resources through XL seawater desalination. The rapid diffusion of XL seawater desalination since 2005, when installed desalination capacity accounted for just 0.3 Mm^3/day, has resulted in a remarkable increase (Palmer, 2012). Today Australia has 72 seawater desalination facilities with a total capacity of 1.8 Mm^3/day (78% of which is designated for municipal use) (MAL, 2013). Eight out of the 72 plants have XL capacity and account for approximately 92% of the total seawater capacity (83% designated for municipalities).

The swiftness with which plans for XL-capacity plants were adopted is notable, given their associated costs. Since 2006, over $\$10^9$ has been invested in infrastructure for six of these plants with significant increases in cost for end-users (Palmer, 2012). Residential consumers in Sydney saw their water bills increase by AU$110/year per household after the Kurnell plant became operational in 2010 (Isler *et al.*, 2010), while the additional cost of the Kwinana plant is AU$36/year for the average customer in Perth (Crisp, 2012). Favorable conditions for seawater desalination in Australia explain diffusion of this technology in part. The concentration of the population in coastal areas allows for lower conveyance costs, making implementation more feasible. Timing was also a factor; the political decisions that paved the way for these projects occurred during the Millennium Drought between 1997 and 2010, thought to be the worst drought on the continent in 1,000 years (Palmer, 2012).

The advent of large-scale desalination has led to new concerns. Australian cities have made an effort to address fears that desalination will be considered as a panacea by ensuring that these projects met with the public's approval. Balancing public opinion with the need to address water security and climate change adaptation has helped Australia earn a reputation as a forerunner in the international market for developing innovative ways in which to offset and mitigate the environmental impact of seawater desalination (El Saliby *et al.*, 2009).

Still, desalination in Australia has been criticized by researchers from the World Wildlife Fund and World Bank (Schenkeveld *et al.*, 2004; Dickie, 2007). In the cases of Perth and Sydney, the earliest adopters of XL seawater desalination, governing authorities viewed the security situation as exigent, calling for 'climate proofing' of the water system (Isler *et al.*, 2010). Expressions of interest were sought for plants to serve Melbourne, Adelaide and Brisbane in 2008, following the opening of the plant serving Perth and a call for tenders for the plant in Sydney the previous year. These critiques suggest that these decisions to rely on infrastructural supply-side solutions were made in undue haste, arguing that seawater desalination should be resorted to only after a deliberative evaluation process that gives due consideration to demand-side and pollution-control measures (Dickie, 2007). These critiques have been somewhat validated in the past 2 years. Following high rainfall in eastern Australia after 2010, and the consequent replenishment of major reservoirs, several XL plants were put on hold or idled in Queensland, Adelaide and Victoria. Proponents, however, argue that desalination is the most sustainable water source in Australia and thus is likely to expand further, although this will require increasing levels of dialogue and coordination (Crisp, 2012).

5.2.4. United States. Although the USA is an 'emerging' country in terms of XL seawater desalination facilities, it is not unfamiliar with the desalination market at large (including all source water types) and actually has the second-highest capacity of desalination in the world, falling behind only Saudi Arabia and narrowly edging out the United Arab Emirates (UAE) (MAL, 2013). The USA has seen a dramatic increase in proposals for XL seawater desalination plants, but these projects have been met with opposition based on economic and environmental grounds. In San Diego County, lawsuits and permit appeals filed by local and environmental groups against the City of Carlsbad XL seawater desalination plant have prolonged its development process, while concerns about co-locating the Camp Pendleton XL plant at a nuclear facility led to two alternative sites being proposed in a 2009 feasibility study (Cooley *et al.*, 2006; Cooley & Donnelly, 2012). The concerns that impeded XL desalination center on energy use and brine disposal.

Even aside from opposition by environmental groups, it has not been a smooth transition into large-scale seawater desalination for the USA. An example of this is the XL seawater desalination plant in Tampa Bay, Florida. The background of the desalination plant is still scrutinized as it has undergone over 12 years of challenges including bankruptcies, cost overruns and technical difficulties (Cooley *et al.*, 2006). Proponents had hoped the Tampa Bay plant would open the door for the diffusion of XL seawater desalination around the country. Instead, it brought into question the economic feasibility of implementing large-scale desalination for municipalities. The initial project budget rose from $110 million to $158 million for remediation work related to filter and membrane failures. With these unanticipated costs, greater uncertainty arose about oversight issues. According to a report by the Congressional Research Service, the Tampa Bay project heightened public awareness of the risks associated with private water developers and competitive bidding on public contracts, without having ‘sufficient external review and accountability mechanisms’ in place (Carter, 2011).

The uncertainty related to financial, social and environmental factors in desalination projects can lead to stakeholder disagreements and a costly and lengthy planning and permitting process (NRC, 2008). In California, up to 26 federal, state and local agencies take part in the review or approval process for a desalination plant (Carter, 2011). This process is an indirect outcome of a 2004 report that cited several issues relating to scale of implementation (Dickie, 2007). The challenge is thus to regulate XL desalination in a way that allows state and local governments to undertake these large-scale projects with reasonable confidence, while still maintaining a streamlined process.

However, even with slow diffusion, it should be noted that states such as Texas, California and Florida are all considering expanding their municipal water portfolios through large-scale desalination projects (Carter, 2011). The interest in seawater desalination parallels a growing concern for local water scarcity and security issues. Support for desalinating groundwater in Texas, for example, has risen after 2 years of drought. Although the state water plan passed in 2012 envisions 3.4% of the state water supply being drawn from desalination plants by 2060, as compared to less than 1% today, the governor’s office has not offered any new public support for desalination (Galbraith, 2012).

Overall, the picture in the USA is of widening use of desalination technologies for brackish and wastewater de-salting, but only a slow rise in XL seawater desalination due to the opposition such plants encounter (Mickley, 2012).

5.2.5. Israel. Historically Israel has had impressive R&D programs in desalination, which led to their being a major exporter of desalination technologies. But until the last decade the country itself only utilized small brackish-water desalination plants in peripheral areas that were not connected to the National Water Carrier (Dreizin *et al.*, 2008). For many years Israel relied upon water conservation and water use efficiency in order to manage their water resources. During this period the treasury blocked all proposals for XL desalination arguing for further water demand management through pricing, while the agricultural lobby blocked rate hikes (Feitelson, 2005). Several extended drought periods and this two-decade policy impasse resulted in the over-exploitation of the water reservoirs. This impasse was broken in 2000 when the decision to embark on large-scale desalination was made. This decision was facilitated by the technological improvements that reduced the cost of desalination (Teschner *et al*., 2013). Since the first XL seawater plant came online in Ashkelon in 2005, desalination capacity has risen rapidly, as two additional XL plants are now operational on the Mediterranean coast. Approximately 42% of the current domestic potable water demand is now supplied through desalination (Feitelson & Laster, 2011). The scale of the push towards XL seawater desalination in Israel is illustrated by the targets outlined in the draft national plan for the development of the water sector. The plan, which has not been ratified yet, proposes an increase in annual capacity to 750 Mm^3 by 2050 (Israel Water Authority (IWA), 2011).

Israel's stated rationales for implementing XL-capacity seawater desalination are similar to those of other emerging countries – improving water quality, reliability, aquifer restoration, drought mitigation and water security. The Israeli government has been successful in promoting the move towards large-scale seawater desalination through the involvement of the public and private sectors as well as economic incentives. This partnership is in tandem with the neo-liberal agenda espoused by the treasury and successive governments since the 1990s, which led to a change of heart in the treasury (Feitelson & Rosenthal, 2012). One particular incentive that the Israeli government has used to reduce uncertainty and promote XL seawater desalination is the allocation of risk through 'Take or Pay' contracts (Feitelson & Laster, 2011). In these contracts the government covers a fixed cost of water even when it is not purchasing it and thus allows the contractors to reduce the overall water price, thereby turning desalinated seawater into the base flow rather than a marginal source (Feitelson & Rosenthal, 2012). Desalination has thus become the main stem of the new water masterplan, supported by most actors, arguably inaugurating a new era in Israeli water policies (Feitelson, 2013).

5.2.6. Overview of emerging country case studies. Table 4 summarizes the main features of the emerging country case studies. In the first column the direct catalyst for advancing desalination is presented. As can be seen, droughts and a sense of impending shortages are often the catalyst. However, in most cases there were also political factors involved. In all cases the desalination was advanced through public-private partnerships (the second column). In the third column the main actors involved in the advancement of desalination are noted. As can be seen, these vary between cases, as the physical, political and institutional scene in each case is different. These variances are indicative of the difficulty inherent in capturing the political-institutional factors in quantitative studies, and thus explain the low level of significance in the quantitative analysis we conducted.

5.3. Incipient countries

At first glance, some countries' move towards XL seawater desalination may pale in comparison to the pioneering countries and forerunning emerging countries in terms of number of facilities and capacity. However, the importance of China and India beginning to implement XL seawater desalination should be noted as it could have a significant impact on the global market in the coming years due to their increasing influence on the global economy (Srinivasan, 2004).

5.3.1. China. China's sheer size presents great variations in the spatial and temporal distribution of its freshwater resources, with plentiful water in the south and water shortages in the north (Zhou & Tol, 2004; Cheng & Hu, 2011). Population growth, together with intense urbanization and industrialization, has begun to severely affect northern China's water balance, limiting socio-economic development in areas with water shortages (Liu & Zheng, 2002). Extensive drought-afflicted areas and the desertification of a wide swath of cultivable grasslands in the north and north-west of the country have drawn new attention to the over-exploitation of groundwater and surface water, as well as existing economic disincentives for sustainable water management (Jiang, 2009). Keeping in line with their large-scale supply-side projects such as dams and south-to-north water transfer schemes to address these critical issues, the country has begun planning and implementing a substantial number of XL seawater desalination projects to serve the 40% of the population concentrated in the coastal areas (Zhang *et al.*, 2005). A high level of investment, both Chinese and foreign, has been observed in China's desalination capacity and it is projected that the nation will be a future major player in the industry, especially in the developing world (Dickie, 2007). Currently, China plans to desalinate nearly one billion m^3/year by 2020, to meet municipal water demand in coastal areas (Cheng *et al.*, 2009), but implementation has fallen behind schedule (Liu & Persson, 2013).

One of the largest barriers to the diffusion of desalination in China is the price of water. Currently, the Chinese government heavily subsidizes the cost of potable water and thus the price does not reflect the true value or economic cost, leading to waste and inefficient use (Zhou & Tol, 2004). In order to promote conservation, raise awareness and remove the barriers to desalination, government policy is needed to lead water price reform. Price reform is the first step towards coupling supply-side solutions with measures for demand management, wastewater recycling, and reallocation of existing water uses in cities (Cheng & Hu, 2011). Greater recognition has been given to the need for better management of existing resources in recent years (Nickum & Lee, 2006).

Growing cognizance of the lack of balance in water supply portfolios indicates that seawater desalination can play an increasingly important role in the future (Liu & Persson, 2013). In terms of XL seawater desalination, China currently has two plants online and four under construction (MAL, 2013). Once the plants currently under construction come online, XL desalinated seawater will account for 33% of the country's seawater desalination capacity, 36% of which is designated for municipalities. However, the role of desalination is likely to increase as an integral part of the multifaceted approach advanced in China to address its worsening water shortages (Cheng *et al.*, 2009; Liu & Persson, 2013).

5.3.2. India. India has also shown a large expansion in proposed desalination capacity, where rapid development is being challenged by unmet water needs. Not only are Indian cities trying to keep up with unprecedented population growth, but incomes and standard of living are also on the rise, making it a major challenge to supply reliable fresh water. As India is faced with unpredictable rainfall, aging infrastructure, and limited reservoir storage, the water scarcity issue is affecting livelihoods as most Indian cities can provide only intermittent water supply to the population (Srinivasan *et al.*, 2010).

Similar to the situation in China, the barrier to the diffusion of desalination beyond the industrial sector in India is the price of water (Dickie, 2007). However, the reason why the population is not willing to pay more than the current price is not due to direct government subsidies but rather the fact that over two-thirds of households have private wells, even in large cities such as Chennai, and do not rely on municipalities for water supply (Srinivasan *et al.*, 2010). This situation threatens future supply as increased exploitation of the aquifers have in turn exposed dangerous soil elements to oxidation, introducing contaminants such as fluorides and arsenic into the water supply (Shah, 1989; Dickie, 2007). Over time, environmental degradation of the aquifers is likely to increase the 'willingness to pay' for a reliable quantity and quality of potable water and thus raise the attractiveness of desalination (Howard & Gelo, 2002). Currently, India has only four XL seawater desalination facilities online, but the desalination market is on the rise in the country with one more under construction (MAL, 2013). Once completed, seawater desalination plants will represent 61% of the country's total desalination capacity.

The extent to which XL seawater desalination should play a prominent role in meeting the water demands of India's growing population will undoubtedly be debated in the years to come. Setting the agenda for water development is a deeply political process, dictated by resistance to water tariff hikes and costly infrastructure development. Faced with the challenge of establishing full cost recovery for water services, financing infrastructure improvements, and enhancing demand management, decision-makers may continue to choose options that could be readily implemented such as urban rainwater harvesting (Srinivasan *et al*., 2010). The rates at which local governments progress in addressing existing constraints to water system reform will differ. Political reticence to do so may slow the rate of diffusion for XL desalination in India. Irrespective of market growth there, desalination will remain as a partial solution for cities, which must be aligned with other programs and policies that support sustainable water management, such as rainwater harvesting during the monsoon season and conservation, water renovation and recycling, and intra- and inter-basin transfers (Gupta & Deshpande, 2004).

6. Discussion

Three factors were hypothesized to drive XL desalination. The first is water scarcity. Hence we can expect XL desalination to take place first in water-stressed areas – mainly arid, semi-arid, and areas with a Mediterranean climate. A look at Figure 3 bears this out. However, physical factors were not statistically significant in the quantitative analysis. This can perhaps be explained by the discrepancy between water availability and national boundaries. As data are compiled by country, they do not necessarily reflect the local intra-country variance in water availability. Thus local scarcities that lead to the construction of XL desalination plants in a particular (dry) part of the country are masked by water availability in other parts of large countries. Moreover, there are very wide differences between countries in seemingly similar physical settings. In particular the rate of change, and hence perceptions of future scarcity, vary. In the logistic regressions the other two factors, population growth and affordability (measured by GDP per capita), indeed seem to have the greatest effect when all factors are considered in tandem. Still, the level of significance of these variables is low, indicating that additional variables are needed to explain the variance in adoption of XL desalination.

The case studies show that the effects of population pressures and affordability on the decision to build XL facilities are mediated by political factors. Thus, in Spain XL desalination allowed an incoming government to cancel a controversial plan to divert the Ebro river water southward. Moreover, desalination in Spain conforms to, and supports, the emerging federalist pressure for greater regional sovereignty over water (Lopez-Gunn, 2009), which is backed by a network of economic and environmental actors (Swyngedouw, 2013). In Algeria XL desalination allowed the government to retain more water in the uplands in order to slow the rural exodus to the highly volatile cities along the Mediterranean (Mahmoudi *et al*., 2009). In Israel XL desalination was embarked upon only when the Treasury came to see it as part of a neo-liberal agenda it espoused to break the monopoly power of the national water company (Feitelson & Rosenthal, 2012).

These cases suggest that one of the attractions of desalination is that it allows decision-makers to circumvent politically sensitive decisions to divert water from existing uses or out of basin. In some cases XL desalination can also circumvent politically difficult demand management practices (such as higher water rates for agriculture). This is largely the case in Australia.

However, desalination may face opposition, which can deter or delay the advent of XL plants. In Israel the treasury was such an opposition for many years, and hence XL desalination was held up due to a political impasse (Feitelson, 2005).[14] In the USA, environmental concerns have delayed XL desalination, largely through court challenges. In countries where desalination is considered, but has not been implemented so far, similar concerns and opposing forces can be expected, but a study of such cases is beyond the scope of this paper. Hence, XL desalination is advanced only when the coalition supporting it is wide and powerful enough to overcome the opposition to such plants.

Another deterring factor is the availability of seemingly cheap fresh water. This is the case in China and India. However, as water abstractions in these countries do not take into account the full range and cost of negative externalities of freshwater extractions from the natural resources, the quality of these resources deteriorates. This has to some extent been the case in Israel, where the postponement of desalination led to over-exploitation of groundwater (Feitelson, 2005). Under such circumstances desalination may become increasingly attractive due to rising quality concerns. However, XL desalination in India and China (as well as in other large emerging economies) is minuscule at present. Thus, while environmental concerns over the effects of desalination may serve as a deterrent in highly developed countries, deterioration in water quality and natural resources in rapidly developing economies may become driving forces for desalination.

Integrating these insights in quantitative analyses is clearly a challenge. Such analyses may try to identify political factors that can be incorporated into logistic regressions. But this may prove difficult due to the wide variety of political factors, as were identified in our case studies, and the wide differences in political structures underlying them.[15] A better approach may thus be to utilize Fuzzy-set Qualitative Comparison Analysis (Ragin, 2000).[16] Such attempts are left, however, for future research.

7. Conclusions

The global diffusion of XL seawater desalination has accelerated in the last decade. Although the arid Arabian Gulf countries and several islands pioneered the industry in the 1980s, they should not be viewed as leaders of the current (second) wave of XL desalination. This second wave of XL desalination is composed primarily of developed and emerging countries who utilize the latest desalination technology (mainly RO) to overcome freshwater deficits. These emerging countries are not limited to arid countries with a water deficit and bountiful energy resources, but include a variety of regions with a wide set of political and socio-economic issues in the water field, as well as islands with low water-retention capacity. While most of these countries and regions are semi-arid or Mediterranean, the factors that determine whether a country embarks on an XL desalination program seem to reflect largely economic, demographic and political factors.

The rapid increase in GDP per capita of mid-income countries, many of which are located (or parts of which are located) in semi-arid or Mediterranean climatic zones, has greatly widened the scope of the

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[14] Essentially, the treasury blocked desalination in order to induce higher rates of water in agriculture while the agricultural lobby in the Knesset (Israel's parliament) blocked such a hike in rates.

[15] Political structures are the sets of institutions, their interactions and the regulations and laws that affect these interactions. In the case of desalination these are the institutional and legal structures that determine the decision-making process regarding XL desalination plants.

[16] We are thankful to an anonymous reviewer for making this suggestion.

XL desalination business. Perhaps the most significant development in the field is the entrance of China and India into the scene. While in both countries low water rates to consumers deter XL desalination at present, the deteriorating quality of natural water resources and rising environmental awareness suggest that the steep part of the S-shaped innovation adoption curve is still ahead of us in the XL desalination field.

However, the decision to embark on an XL desalination program is ultimately a political decision.[17] This decision is influenced by political structures and factors that differ across countries. Still, several generalizations regarding these factors can be made on the basis of the case studies. Desalination is advanced when it conforms to governmental agendas (such as the neo-liberal agenda in the Israeli case, or the mitigation of rural exodus in Algeria) or when it allows the government to elude other politically costly options for addressing water shortages. In particular, desalination may replace politically sensitive water transfers or politically costly demand management measures. The seeming trade-off between desalination and water demand management has been one of the focal points of the critiques leveled at desalination by some analysts and environmentalists. The power of these groups vis-à-vis the power of players promoting XL desalination will determine the decisions to embark on XL desalination in specific locales. But, when taking a global view, it is undoubtedly true that the march is on, and XL desalination will continue to diffuse at a rapid pace, as demand management has limitations. Thus, even in cases where demand management is well advanced, such as in Israel, desalination becomes increasingly attractive. Therefore, the question is not whether XL desalination will increase, but at what rate and where will it do so.

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[17] This statement is true only for XL desalination plants, as small plants can be built by private entrepreneurs, often to supply tourist resorts in arid areas or industrial plants.

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