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A seawater desalination scheme for global hydrological models

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Supplemental Text

Selection criteria of desalination plants

We subscribed to the DesalData (http://www.desaldata.com) desalination database and downloaded all of the data available as of June 2014, including information on desalination plants of various sizes, source water, and year of construction. To estimate seawater desalination globally for domestic and industrial purposes at a spatial resolution of 0.5°×0.5°, we selected the data to include in our analyses. Among the many data fields available, we focused on plant status, year online, water type, user category, and plant size (see Table S2). First, we selected "online" plants and discarded those with other statuses ("construction," "planned," "canceled," "on hold," "offline," and "unknown"). We set 2005 as the base year, and selected the plants that had started operation in 2005 or earlier. Since we focused on seawater desalination, we selected plants using "brine or concentrated seawater" and "seawater" and excluded those using other water types. Then, we selected plants producing water for "municipalities as drinking water" and "tourist facilities as drinking water," which correspond to municipal water in the text, and "industry", "military purposes", and "power stations" for industrial water. We also included plants for "irrigation." As stated in the text, at

least at the time of publication, desalination is seldom used for irrigation. Exceptionally, four major desalination plants were constructed for irrigation in Spain up until 2005. Plants for other purposes (demonstration, discharge, process, water injection, and unknown) were excluded. Finally, we selected plants with capacities exceeding 10,000 $m^3\ d^{-1}$. This corresponds to water resources of approximately 1.5 mm yr^{-1} assuming the area of a grid cell is 2500 km^2 (0.5°×0.5°), which is the same order of magnitude as other water resource components simulated in H08. This also excluded pilot plants, since the goal of this study was to develop a model to identify regions regularly supplied by seawater desalination.

Method summary in Figure 5

Municipal and industrial water use in areas utilizing seawater desalination (AUSD; the horizontal axis in Figure 5) was estimated as follows. AQUASTAT reports sector-specific national water withdrawal for 5-year intervals from 1980 to 2005. We collected all of the data available for major countries. We also used the national water statistics of Qatar (MDPS, 2016), which includes a sector-specific time series record of water use. Then, we spatially distributed each record into the 0.5°×0.5° grid cells by weighting population density for circa 2000. Next, we masked the gridded water

37 withdrawal by AUSD in 2005, and estimated the total municipal and industrial water
38 withdrawal in AUSD. Finally, using the project completion year in DesalData, we
39 obtained the total desalination capacity (the vertical axis in Figure 5) for each country
40 and period. AUSD was fixed at 2005 assuming that climate conditions were unchanged.
41
42 **Estimation of unit production cost**
43 We used information on the engineering procurement and construction costs
44 [hereafter EPC] for the 173 major plants reported in DesalData. First, we examined
45 whether there were any clear tendencies pertaining to costs among countries, regions,
46 user categories, or years of construction. We found distinct differences in the costs of
47 membrane processes (e.g., reverse osmosis and electrodialysis) and thermal
48 technologies (e.g., multi-stage flash and multi-efficient distillation). In the future
49 simulation, we assumed that new plants would use membrane processes because of their
50 greater efficiency.
51 Lamei *et al*. (2008) estimated the unit production cost (0.86–3.21 USD m^{-3}) for
52 membrane desalination plants in Egypt, Saudi Arabia, and several other countries. The
53 unit production cost includes the unit capital cost and operation and maintenance costs
54 (O&M cost; including the costs for pre- and post-treatment chemicals, membrane

55 replacement, energy, labor, brine disposal, and administration divided by the annual
56 plant production). The former is defined as the annualized EPC divided by the plant
57 capacity. As the latter is seldom reported, the O&M cost was assumed to be 150% of
58 the unit capital cost based on a literature survey, which assumed a plant life of 20 years
59 and a discount rate of 8%. Adopting their methodology, we estimated the unit
60 production cost at 0.40–3.78 USD m^{-3} from the EPC of 63 plants using membrane
61 process desalination.
62
63
64

Supplemental Figures

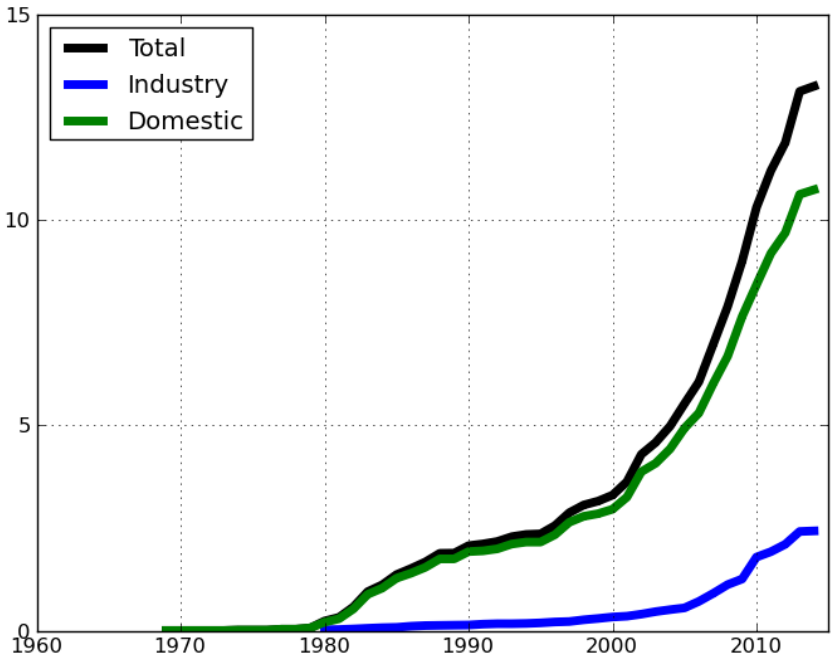


Figure S1. Historical change in the global total seawater desalination capacity ($km^3\ yr^{-1}$).

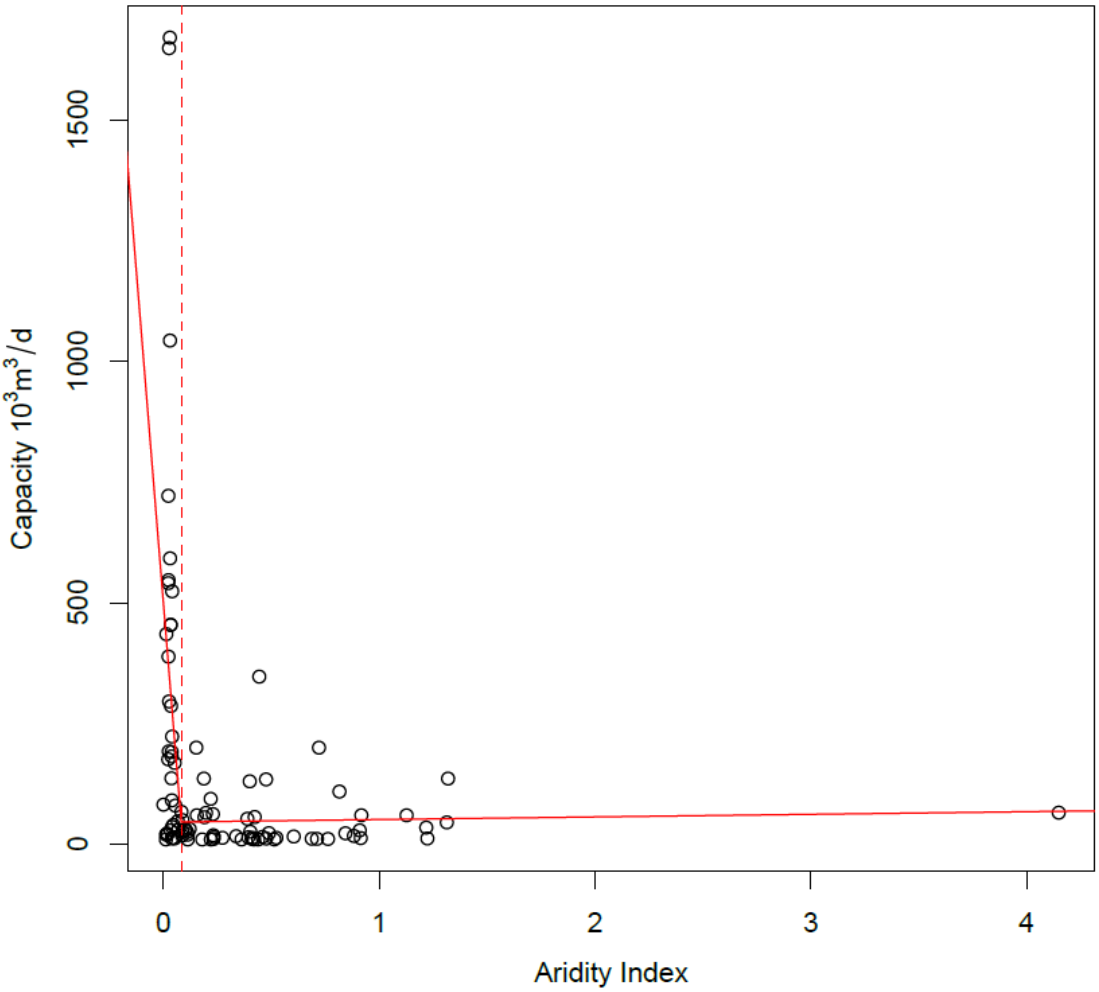


Figure S2. The relationship between the aridity index and capacity of desalination plants using the results for 94 grid cells. Red lines show the regressions obtained by applying the segmented regression method. Dashed line represents the break point (Aridity index= 0.082).

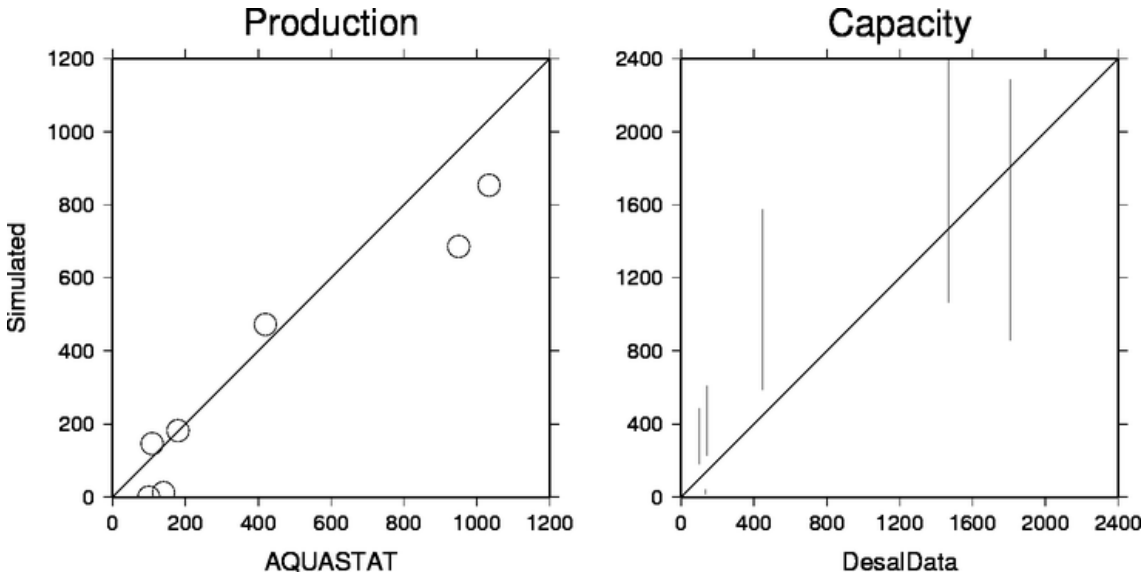


Figure S3. Production of seawater desalination and capacity of the major countries shown in Table 1 (10^6 m^3 yr^{-1}). The range of simulated capacity shows the uncertainty in the production-to-capacity ratio, which is assumed to be 30–80% in this study.

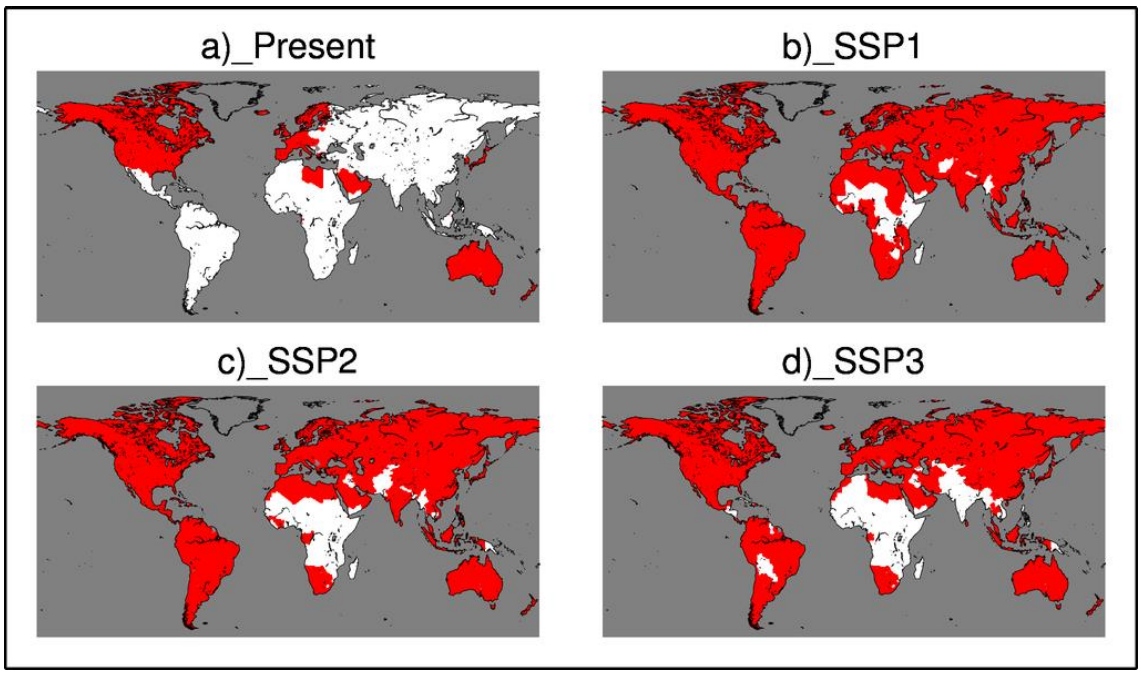
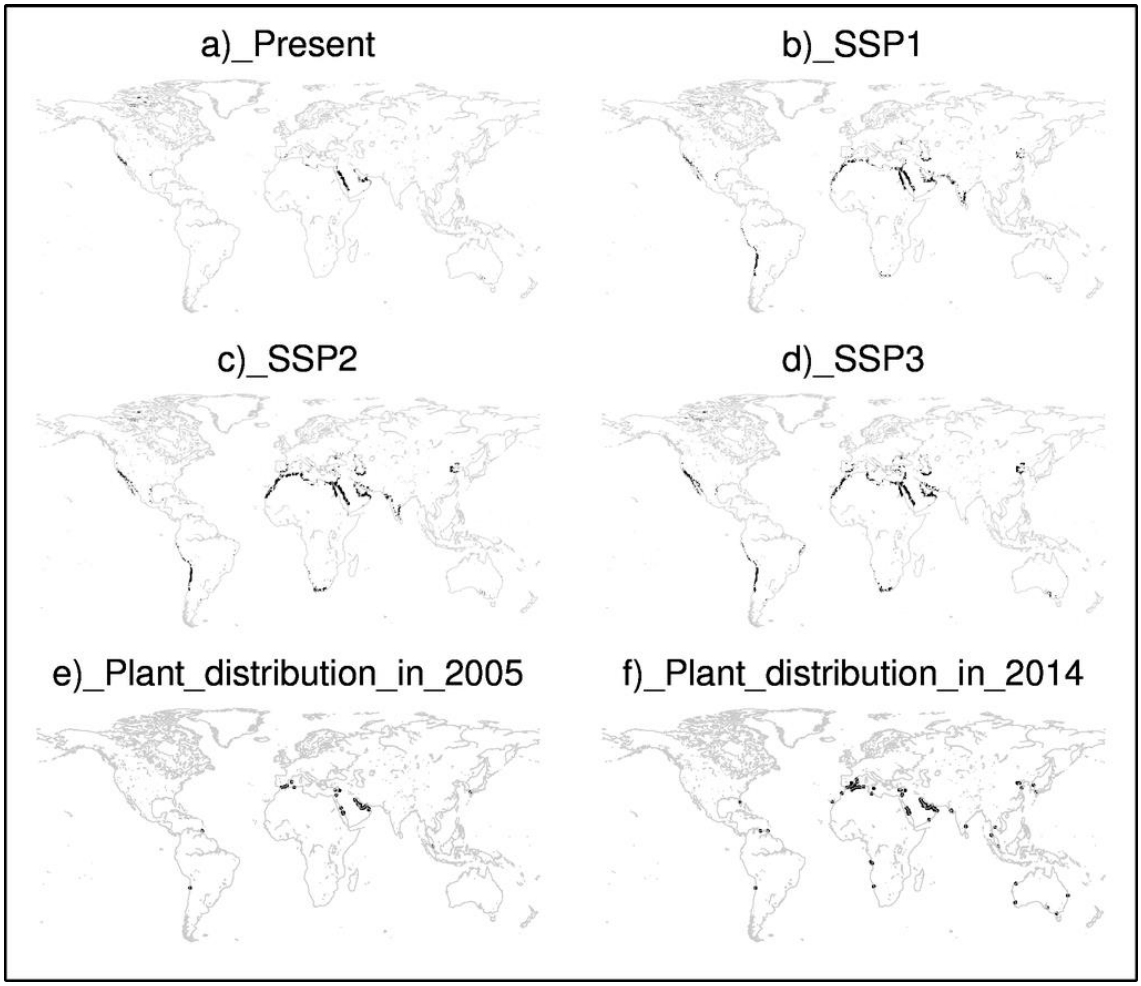


Figure S4. Countries with a per capita gross domestic product (GDP) exceeding 14,000 USD purchasing power parity (PPP) per capita.



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88 **Figure S5**. Global distributions of areas utilizing seawater desalination (AUSD) using
89 SDM2 in (a) 2005, (b) SSP1 in 2055, (c) SSP2 in 2055, and (d) SSP3 in 2055.
90 Locations of seawater desalination plants larger than 50,000 m^3 day^{-1} in capacity in
91 (e) 2005 and (f) 2014.

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Supplemental Tables

Table S1 Data items and selection

Items	Options	Selection
Plant status	Online, Presumed online	Included
	Construction, Planned, Canceled, On hold, Offline, Unknown	Excluded
Water type	Brine or concentrated seawater (TDS > 50,000 ppm),	Included
	Seawater (TDS 20,000–50,000 ppm)	
	Brackish water or inland water (TDS 3000 to < 20,000 ppm),	Excluded
	River water or low concentrated saline water (TDS 500 to < 3000 ppm),	
	Pure water or tap water (TDS <500 ppm),	
	Waste water, Unknown	
User category	Municipalities as drinking water (TDS 10 to <1000 ppm),	Included
	Tourist facilities as drinking water (TDS 10 to <1000 ppm),	
	Industry (TDS <10 ppm),	
	Military purposes (TSD 10 to < 1000 ppm),	
	Power stations (TDS < 10 ppm),	
	Irrigation (TDS < 1000 ppm)	
	Demonstration, Discharge, Process, Water injection, Unknown	Excluded
Plant size	Extra-large (Capacity ≥ 50,000 m^3 d^{-1}),	Included
	Large (50,000 > Capacity ≥ 10,000 m^3 d^{-1})	
	Medium (10,000 > Capacity ≥ 1000 m^3 d^{-1}),	Excluded
	Small (1000 m^3 d^{-1} > Capacity)	

Table S2 Excluded desalination plants and reasons for their exclusion. 1 and 2 in the column Reasons for exclusion indicate substantially far from the seashore (distance from the seashore) and apparent inconsistency in location records (name of city, country, longitude/latitude do not match), respectively.

Name of plant	Country	Reasons for exclusion
O.I. SW 12.500	Algeria	1 (910 km)
Block 31 Field	Angola	1 (529 km) and 2
Kizomba A	Angola	1 (831 km) and 2
Kizomba B	Angola	1 (831 km) and 2
Pazflor FPSO	Angola	1 (529 km) and 2
Pazflor FPSO	Angola	1 (529 km) and 2
Plutao, Saturno, Venus, and Marte (PSVM)	Angola	1 (529 km) and 2
P63	Brazil	1 (946 km) and 2
Petrobras P57	Brazil	1 (946 km) and 2
Revap	Brazil	1 (946 km) and 2
RLAM ETA	Brazil	1 (946 km) and 2
Sao Paulo	Brazil	1 (946 km) and 2
SBM Cidade De Paraty	Brazil	1 (946 km) and 2
Tupi 2	Brazil	1 (946 km) and 2
China Petroleum & Chemical Corporation Methanol Filtration Project	China	1 (1449 km) and 2
Huanghua	China	1 (897 km) and 2
Iron & Steel Group Wastewater Reuse Project	China	1 (1449 km) and 2
Pinghai Power Plant	China	1 (1449 km) and 2
Rongcheng	China	1 (751 km) and 2
Yan Hu Lan Ke SWRO Plant	China	1 (1449 km) and 2

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Name of plant	Country	Reasons for exclusion
Yin Kou	China	1 (1449 km) and 2
YueQing	China	1 (782 km) and 2
Yuhuan	China	1 (782 km) and 2
India	India	1 (472 km) and 2
Santej	India	1 (430 km) and 2
Iran	Iran	1 (380 km)
Kensalt	Kenya	1 (439 km) and 2
Soussa	Libya	1 (405 km) and 2
Soussa II	Libya	1 (405 km) and 2
Zuetina II	Libya	1 (492 km) and 2
Russia	Russia	1 (1473 km)
Russia	Russia	1 (1473 km)
Tobolsk	Russia	1 (918 km)
Tobolsk	Russia	1 (918 km)
Tobolsk	Russia	1 (918 km)
Al Hota	Saudi Arabia	1 (388 km)
Al Qurayyah	Saudi Arabia	1(533km) and 2
Assir	Saudi Arabia	1 (183 km)
Assir	Saudi Arabia	1 (183 km)
PP11	Saudi Arabia	1 (388 km)
Riyadh	Saudi Arabia	1 (388 km)
Shas Water Treatment	Saudi Arabia	1 (388 km)
Sureste 1	Spain	2

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Name of plant	Country	Reasons for exclusion*
Sureste 2	Spain	2
Tenerife	Spain	1 (307 km)
Colakoglu	Turkey	1 (277 km) and 2
Eren Eneril	Turkey	1 (184 km) and 2
Eren Project	Turkey	1 (247 km) and 2
Nuh Cimento expansion	Turkey	1 (197 km)
Steel Mill MMK Atakas	Turkey	1 (194 km)
Turkmenistan	Turkmenistan	1 (596 km)
Mobile Unit	U.S.A.	1 (1178 km)
U.S.A.	U.S.A.	1 (1178 km)
Yuzhniy	Ukraine	1 (347 km) and 2

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Table S3 The number of desalination plants and their capacity sorted by categories. Size, Type, Status, and User stand for Plant status, Water type, User category, and Plant size in Table S1. O/PO in Status and MTIMPI in User stand for Online and presumed online, Municipalities Tourist facilities, Industry, Military purposes, Power stations, and Irrigation in Table S1. QC stands for quality check of location of plants, or exclusion of erroneous records listed in Table S2.

Size	Type	Status	User	QC	Number of plants 1990	Capacity [km^3 yr^{-1}]	Number of plants 2005	Capacity [km^3 yr^{-1}]	Number of plants 2014	Capacity [km^3 yr^{-1}]
All	All	All	All	No	5,594	5.4	12,204	14.6	17,335	31.4
All	All	O/PO	All	No	1,830	3.1	8,418	12.1	13,368	26.1
All	Seawater	All	All	No	1,583	3.5	3,813	8.1	5,673	19.2
All	Seawater	O/PO	All	No	726	2.4	2,946	6.9	4,708	15.7
L, XL	Seawater	O/PO	MTIMPI	Yes	65	1.9	240	5.3	559	12.7

116 **Table S4** Regional classification

Region	Countries (ISO 3166-1 alpha 3)
Sub-Saharan Africa	AGO BDI BEN BFA BWA CAF CIV CMR COD COG COM CPV DJI ERI ETH GAB GHA GIN GMB GNB GNQ KEN LBR LSO MDG MLI MOZ MRT MUS MWI NAM NER NGA RWA SEN SLE SOM STP SWZ SYC TCD TGO TZA UGA ZAF ZMB ZWE
Centrally Planned Asia and China	CHN HKG KHM LAO MAC MNG VNM
Central and Eastern Europe	ALB BGR BIH CZE EST HRV HUN LTU LVA MKD MNE POL ROU SRB SVK SVN
Former Soviet Union	ARM AZE BLR GEO KAZ KGZ MDA RUS TJK TKM UKR UZB
Latin America and the Caribbean	ARG ATG BHS BLZ BOL BRA BRB CHL COL CRI DMA DOM ECU GRD GTM GUY HND HTI JAM KNA LCA MEX NIC PAN PER PRY SLV SUR TTO URY VCT VEN
Middle East and North Africa	ARE BHR DZA EGY IRN IRQ ISR JOR KWT LBN LBY MAR OMN QAT SAU SDN SYR TUN YEM
North America	CAN USA
Pacific OECD	AUS JPN NZL
Other Pacific Asia	BRN FJI FSM IDN KIR KOR MMR MYS PHL PLW PNG SGP SLB THA TON VUT WSM
South Asia	AFG BGD BTN IND LKA MDV NPL PAK
Western Europe	AUT BEL CHE CYP DEU DNK ESP FIN FRA GBR GRC IRL ISL ITA LUX MLT NLD NOR PRT SWE TUR

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Table S5 Desalination cost [10^6 USD yr^{-1}]. See Table S4 for the classification of countries.

Region	2005	2025			2055		
		SSP1	SSP2	SSP3	SSP1	SSP2	SSP3
Sub-Saharan Africa	0–0	2–17	3–25	3–27	76–716	67–635	24–231
Centrally Planned Asia and China	0–0	0–0	0–0	0–0	0–0	0–0	0–0
Central and Eastern Europe	0–0	0–0	0–0	0–0	0–0	0–0	0–0
Former Soviet Union	0–0	7–66	9–82	13–119	5–50	17–158	21–203
Latin America and the Caribbean	0–0	463–4,374	577–5,448	686–6,484	390–3,686	738–6,977	1,158–10,947
Middle East and North Africa	956–9,030	982–9,277	1,341–12,675	1,475–13,943	6,098–57,626	15,044–142,166	17,956–169,683
North America	163–1,545	163–1,536	207–1,955	232–2,188	124–1,174	255–2,412	290–2,742
Pacific OECD	3–31	4–39	2–16	3–32	2–18	1–10	5–46
Other Pacific Asia	0–0	0–0	0–0	0–0	0–0	0–0	0–0
South Asia	0–0	0–0	0–0	0–0	786–7,425	0–0	0–0
Western Europe	0–0	0–0	0–0	0–0	0–0	0–0	0–0
Global	1,122–10,606	1,620–15,310	2,138–20,201	2,412–22,793	7,481–70,695	16,123–152,358	19,455–183,851

Table S6 Desalination cost as fraction of regional or global GDP [%]. See Table S4 for the classification of countries.

Region	2005	2025			2055		
		SSP1	SSP2	SSP3	SSP1	SSP2	SSP3
Sub-Saharan Africa	0–0	0–0	0–0.001	0–0.001	0–0.003	0–0.004	0–0.002
Centrally Planned Asia and China	0–0	0–0	0–0	0–0	0–0	0–0	0–0
Central and Eastern Europe	0–0	0–0	0–0	0–0	0–0	0–0	0–0
Former Soviet Union	0–0	0–0.001	0–0.002	0–0.002	0–0	0–0.002	0–0.003
Latin America and the Caribbean	0–0	0.005–0.044	0.006–0.055	0.007–0.065	0.002–0.015	0.003–0.033	0.007–0.065
Middle East and North Africa	0.032–0.306	0.014–0.133	0.019–0.181	0.021–0.202	0.03–0.286	0.084–0.791	0.121–1.147
North America	0.001–0.011	0.001–0.007	0.001–0.009	0.001–0.011	0–0.003	0.001–0.008	0.001–0.011
Pacific OECD	0–0.001	0–0.001	0–0	0–0.001	0–0	0–0	0–0.001
Other Pacific Asia	0–0	0–0	0–0	0–0	0–0	0–0	0–0
South Asia	0–0	0–0	0–0	0–0	0.001–0.014	0–0	0–0
Western Europe	0–0	0–0	0–0	0–0	0–0	0–0	0–0
Global	0.002–0.019	0.001–0.012	0.002–0.017	0.002–0.020	0.002–0.022	0.006–0.060	0.011–0.100