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Projections of future desalination capacity and related risks of maladaptation

Marina Andrijevic[1], Adriano Vinca[1], Edward Jones[2], Michele Magni[2], Michelle van Vliet[2], and Edward Byers[1]

[1]International Institute for Applied Systems Analysis, Energy, Climate and Environment, Austria (andrijevic@iiasa.ac.at)
[2]Utrecht University, The Netherlands

The intensifying global water crisis calls for novel strategies to ensure reliable, equitable, and sustainable water supply. As climate change, population growth, and overuse of conventional freshwater sources push water systems beyond safe planetary boundaries, novel technologies are becoming increasingly central to adaptation strategies. Desalination stands out as a critical yet contested option to enhance water security, particularly in regions exposed to persistent aridity and rising water stress. While technologically mature and rapidly expanding, future developemtn of large-scale desalination capacities remains underexamined as a potential source of maladaptation due to its high energy demand and potential carbon footprint.

Using the data on individual plants from Global Water Intelligence, in this study we provide a global assessment of the evolution and future prospects of desalination. Historical timeseries on capacities of key desalination technologies were combined with climate and socioeconomic indicators into a panel dataset to analyze historical growth patterns and project future trajectories under different Shared Socioeconomic Pathway (SSP) scenarios. Applying random forest regression models, we identified key predictors of national desalination capacity—namely water stress, aridity ,income, population, and urbanization—as drivers of observed and projected trends.

Historically, global desalination capacity expanded from about 250,000 m³/day in 1980 to 122 million m³/day by 2020. While dominated by high-income and arid countries in the past, desalination is projected to accelerate in developing regions—particularly Africa and South Asia—driven by population growth and rising economic activity. Cumulative capacity is projected to at least double (SSP3) or nearly triple (SSP1) by 2060. Scenario comparisons show that socioeconomic development, more than climate dynamics, shapes the scale of desalination dynamics.

To evaluate the emissions footprint of future desalination, we linked energy demand estimates (Magni et al., 2025) with scenario-based assumptions on growth in desalination capacity, including various technological compositions. We find that, owing to population- and economic activity-driven demand for desalinated water, in the scenario of high economic development but continued and increased fossil fuel emissions peak around the year 2070 at around 550 MtCO2/year, but they decrease only to around 400 MtCO2/year later in the century, which is still

twice the current levels. In a fragmented development-high emissions scenario, emissions steadily rise to around 300 MtCO2/year in 2100. For a high development-fast decarbonization scenario, emissions from desalination become neutral past 2070.

Our findings highlight desalination's dual role as both an enabler and potential risk in climate adaptation pathways. Scaling desalination as a sustainable non-conventioonal water (NCW) solution will require integrating renewable energy supply, technological innovation, and proactive governance to minimize maladaptive outcomes. This research informs global debates on water security by quantifying the balance between desalination's adaptation benefits and its climate-related costs, emphasizing its role within equitable and low-carbon NCW portfolios.