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Desalination projects economic feasibility: A standardization of cost determinants

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ABSTRACT

In order to counter growing shortages in water supply, there has been an increasing adoption of non-conventional sources, such as desalination. As a matter of fact, the marginal costs of water (*i.e.*, production) or, in a different perspective, the potential and limitations of different technologies, make the use of particular types of desalination methods an increasing possibility. The growing use of hybrid systems highlights the acknowledgment of those technologies as accepted opportunities to diversify water sources, and from a different perspective, render desalination solutions more efficient and effective. Thus, the study of cost determinants which confer a dynamic importance to such technologies is paramount and policy relevant. For that purpose, cost structures and cost determinants were standardized in order to provide guidelines, or a basis, for a suitable cost perception. This paper provides relevant insights of desalination projects' key factors, and to such an extent, this is a significant contribution. In this analysis, the results achieved compare possible energy solutions, mainly targeting renewable prospects, due to their impact on the total cost of produced water. The economic feasibility of different desalination technologies and energy solutions is also assessed, with a significant focus on possible hybrid possibilities and the site-specificity of such projects, due to their importance and impact on future technology trends and their cost variations.

1. Introduction

In 2010, the supply of clean drinking water was explicitly acknowledged by the United Nations (UN) as essential to the fulfillment of all human rights [1], however, in many situations such valuable resource is not available in acceptable quantity or quality. Indeed, current water supplies due to either natural restrictions or lack of infrastructure (or both) fail to provide, in a sustainable way, for all the increasing and competing uses (*e.g.*, residential, industrial, agricultural) [2–5]. Historically, the cost of water supply infrastructure led utilities to resort to freshwater sources (*e.g.*, surface and groundwater); yet, their depletion or overexploitation, contamination or, in short, the comparative cost of available technologies, drove the focus to the creation of countermeasures.

In accordance with Moser et al. [6], those countermeasures fall under the following categories:

- Increases in productivity, mainly by promoting improved practices and wastewater reuse;
- Reduction in demand, by encouraging efficient or controlled consumption;
- Expansion of supply, by diversifying to non-conventional sources as desalination.

Furthermore, the differences in marginal costs, limitations and potential (*e.g.*, location near the source/feed water, cost of energy), make their study significant and able to achieve policy relevant contributions [7]. In this analysis, we will focus on the last one, precisely on the diversified desalination technologies, highlighting their dynamic importance depending on the inherent cost determinants [8]. In order to achieve that, it is paramount to characterize such industrial production processes by their components (as suggested by Barak [9]). Those can be labeled as the inputs, the outputs and the process itself, and each has different characteristics and varies significantly across alternatives with serious cost impacts. Besides, the costs of the project also vary depending on the location (*i.e.*, exogenous conditions that are site-specific). See Fig. 1 for the general characteristics of a desalination process (features adapted from Ettouney [10], Bleninger et al. [11], WRF [12]).

As seen in Fig. 1, the main inputs are the feed water, as well as the energy and chemicals required. Related to the feed water, the importance relies mostly on its mineral quality (*e.g.*, salinity) due to its

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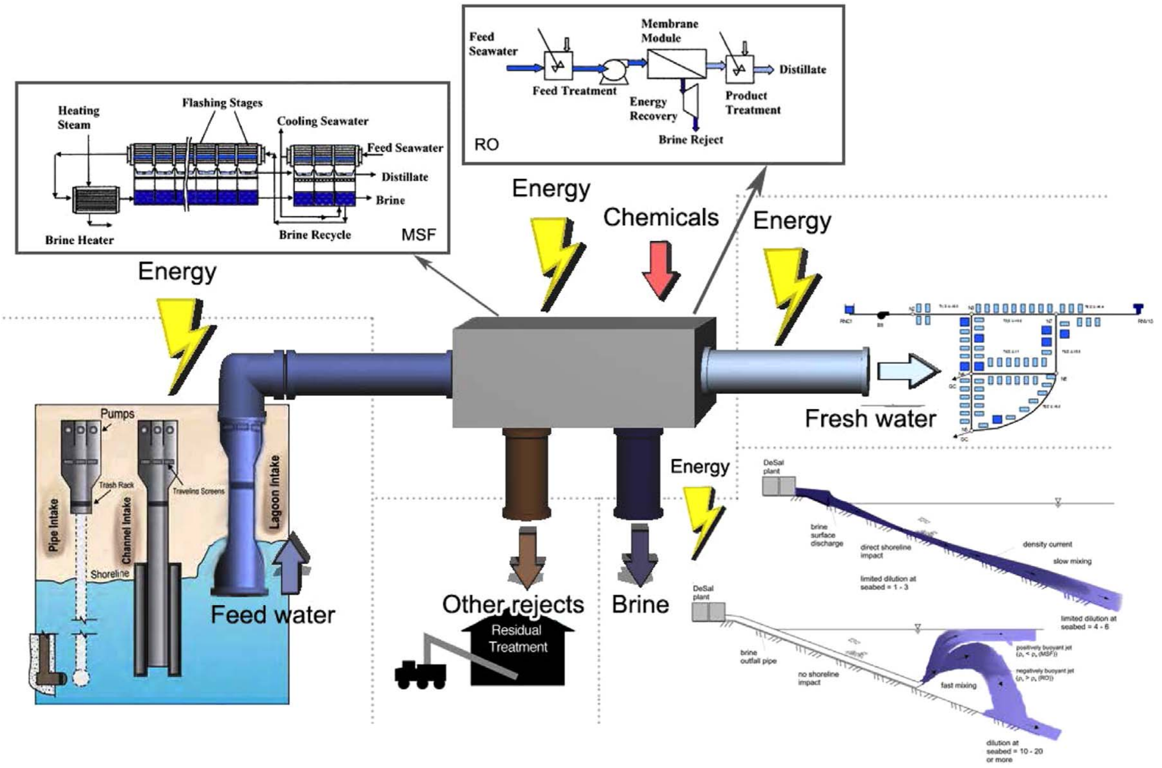

Fig. 1. Possible general features of a desalination process.

impact in choosing a suitable technology. In fact, there is a widely recognized salinity threshold of 500 ppm (total dissolved salts) in order to avoid health problems and a reduced infrastructure lifespan. The World Health Organization updated in 2011 that value up to 600 [13], and in particular cases a value of 1 000 ppm may also be considered. Usually, seawater has a salinity range between 35,000 and 50,000 ppm, demanding a thorough removal (for an example of a desalination process and its removal characteristics analysis, see Dao et al. [14]). The organic load (*e.g.*, algal biomass) is another feed water important component that may cause serious issues at the operational level, requiring costly pretreatment systems or even plant off-line periods [15].

The energy and chemical requirements are relevant inputs that are process specific. The high energy consumption raises awareness due to its dependence on fossil fuels and, thus, the green house gases (GHG) emission they end up generating. Those concerns endorsed the integration of renewable energy resources in desalination [16,17].

Currently there are several available technologies that can be categorized according to the use of phase change thermal processes or to the use of membrane processes [18], additionally there is also the possibility of recognizing hybrid situations [19]. The phase change thermal processes involve a temperature increase in order to reach the feed water's saturation temperature at operating pressure, upon which there is a separation through evaporation. Afterwards, the resulting steam is condensed in a different heat exchanger to produce fresh water [17]. The most widely adopted applications are: the multi-stage flash distillation (MSF); the multi-effect distillation (MED), and the vapor compression evaporation (VC).

As for the membrane processes, they use a semi-permeable membrane barrier to filter the passage of certain ions (in general also preventing the passage of larger and unwanted molecules such as viruses and bacteria). The vast amount of applications differ on their driving force which ranges from pressure (*e.g.*, reverse osmosis - RO; nanofiltration - NF), to concentration gradient (*e.g.*, forward osmosis - FO) and electrical potential (*e.g.*, electrodialysis - ED; electrodialysis reversal - EDR). Usually, this type of processes (*i.e.*, membrane related) is highly dependent on the type of feed water, having relevant differences in process design and cost impacts depending on its salinity [20].

The hybrid methods are a combination of membrane and thermal techniques (*e.g.*, membrane distillation - MD) or processes (*e.g.*, MED or MSF coupled with RO or NF) [21]. In fact, following the same authors, since the beginning of the 21st century that the evolution of processes and techniques has been daunting, but due to information availability and the relevance of their application, we will focus mainly on the previously identified ones.

As for the outputs, we highlight the quality requirements related to the desalted water (for general purposes considered as fresh water) and the rejects obtained throughout the desalination process as the brine and other process specific rejects. The intended final quality may require adaptations to prevent problems associated with bitter or salty taste (and other organoleptic characteristics), hardness, scale formation and fouling [22]. Moreover, the rejects generated, and their disposal, may raise concerns due to potential environmental problems [23]. Worldwide desalination plants extract large volumes of water and discharge a brine concentrate that can potentially harm, in both physicochemical and ecological attributes, the receiving environments [24]. The remaining key residuals generated, which can be characteristic from particular procedures, include 'pretreatment process waste streams' and 'spent membrane cleaning solutions' [20].

The previously mentioned characteristics have an influence in the total investment and in the produced water costs, which are key parameters to the decision makers, being policy relevant. However, in several of the studies that assess economic evaluations, the costs incurred are detailed for specific situations (see Fthenakis et al. [25] for a case-study) and/or compared in different ways. This predicament may result in the lack of a reliable 'schematization' to develop a comparative project analysis, being important to avoid the inclusion of (when not detailed) not only the distribution costs, due to non-revenue water, but also administrative and conveyance costs along with a possible profit to the provider, as they have great variation and misrepresent cost comparisons.