Assessment of methodologies and data used to calculate desalination costs

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\textbf{ARTICLE INFO}
\textbf{ABSTRACT}

In desalination, similarly with other industries, the cost of the final product is one of the most important criteria that define the commercial success of a specific technology. Therefore, when new projects are planned or new technologies are proposed, the analysis of the expected costs attracts a lot of attention and is compared to (perceived) costs of state-of-the-art desalination or costs of alternative fresh water supply options. This comparison only makes sense if the cost assessment methodologies are based on the same principles and use common assumptions. This paper assesses: (i) the methodologies used to calculate the water cost; (ii) the boundary conditions and (iii) the input data and assumptions. It has been found that most papers in the literature use different assumptions and data sources. This has led to difficulties in objective comparisons between these methodologies, definitions and data sources used to calculate desalination costs make difficult objective comparisons between technologies.

1. Introduction

The combined effects of global population growth, industrialisation and urbanisation drive an increasing demand for water. UNEP predicts that by 2025 > 2.8 billion people in 48 countries will face water stress or scarcity conditions [1]. In many regions of the world, desalination is one of the strategies adopted in order to deal with this issue. As a result the relevant market is growing rapidly. The global desalination capacity in 1980 was about 5 million m\textsuperscript{3}/year [2] increasing to about 90 million m\textsuperscript{3}/year by 2016 [3]. Between 2005 and 2015 alone the desalination capacity in the world has more than doubled and this trend continues [3].

The preferred type of desalination process and the sources of energy used change over time depending on technological developments, which affect both the performance and the cost of the desalination and energy generation technologies. In addition, the technological preferences are greatly affected by the local conditions in the regions where the plants are installed because parameters such as the cost of fuel and the typical feed water composition can vary widely, affecting the performance and feasibility of the plant.

In most countries water supply is the responsibility of municipalities, or some other kind of governmental agencies. Therefore, these agencies and the companies that are supporting them in the process face the following choices:

- Shall they employ desalination, or is there a better alternative for securing the necessary resources for their water supply needs?
- If desalination is employed, which is the most suitable technology for their specific conditions?
- Which source(s) of energy should be used to power the inherently energy intensive desalination process?

The issue of cost is central in dealing with these questions. Of course other parameters are also taken into account in the decision process, such as environmental impacts, social acceptance and strategic choices defined by governmental policies. But in any case, no decision can be taken without full clarity on the economics of each choice.

The importance of the desalination costs is reflected on the large amount of relevant scientific papers and reports that deal directly with this issue. It has been widely acknowledged [4–7] that the different methodologies, definitions and data sources used to calculate desalination costs make difficult objective comparisons between technologies
and between different projects. There have been efforts in developing a
global picture about this issue and streamlining the approaches fol-
lowed by the desalination community. Most notably, in December 2004
MEDRC started a process aiming to develop a global standard for de-
salination cost calculations. The first step was a dedicated conference in
Larnaca, Cyprus, where invited papers by leading experts were pre-
seated on issues like: (i) Desalination technology costs [8–14], (ii) Cost
models [15–21], (iii) Boundary conditions [22–26], and (iv) Case stu-
dies [27–34]. The idea was that the conference would be followed by a
“book that will be useful to decision makers, planners and the industry”
and “ultimately develop a dynamic standard that is globally accepted”
[4]. However, these follow-up actions were never organised and no
other dedicated action or event has taken place since.

This paper aims to pick-up on this process and contribute to the
development of increased understanding a common practices within
the desalination community. Over 100 publications from the past
20 years (1996–2016) have been critically reviewed, focusing mainly
on the methodologies, the assumptions and input data that they use,
rather than the actual results of desalinated water cost in USD/m³. Then
the strengths and weaknesses of each approach are discussed, coming
up with suggestions for desalinated water cost calculations that are
reliable, defining the extent to which they can be used for different
decision making processes or other purposes.

2. Literature on desalination cost reviews and correlations

2.1. Cost reviews

There are several studies that have reviewed published desalination
costs. In 2008 Karagiannis et al. [35] reviewed almost 100 different
cases and classified the reported costs into categories according to the
type of feed water (i.e. seawater, brackish etc.), the desalination process
adopted (i.e. RO, MED, MSF) and the type of energy source (heat, re-
newable electricity or grid electricity). In 2014, Shatat et al. [36], also
screened desalination costs from various sources and grouped them in
tables classified by technology and energy source. The cost data come
mostly from the previously mentioned work of Karagiannis and from
few other published papers with original cost calculations. In 2013, Al-
Karaghoulia et al. [37] did a similar work, where cost data from 23
publications were used to develop a table providing cost ranges for all
major desalination technologies powered by conventional sources and
another 29 papers were used to compile a similar table with the costs of
desalination powered by renewable energy. Also Ziolkowska in 2015
[38] presented an analysis where over 50 papers, reports and databases
have been used and the costs reported have been discussed, providing
also a cost breakdown to operating, maintenance and capital cost. All
these papers [35–38] classify costs based on technology and energy
source and sometimes plant size; however the grouping of the costs in
each of these papers does not take into account critical factors, such as:

(i) The different year of construction. For example, Al-Karaghoulia et al.
in their paper in 2013 [37] derived a cost range for PV-RO from 11.7
to 15.6 USD/m³ by grouping together costs taken from papers
published from 1991 [39,40] up to 2009 [41].

(ii) The different geographical locations. For example Karagiannis et al.
[35] gave a cost range from 0.48 to 1.62 USD/m³ for RO systems
with capacities from 15,000 to 60,000 m³/day, grouping together
data from countries with very different conditions such as USA,
China, Greece and UAE.

(iii) The assumptions/methodologies used to derive these costs. For ex-
ample Ziolkowska [38] grouped together costs reported in the
Global Water Intelligence (GWI) database from real desalination
plant EPC contracts, cost assessments from the literature and re-
results she derived from applying the DEEP 5 model developed by
the International Atomic Energy Agency.

By grouping together information without accounting for these
three factors the conclusions can be misleading. As will be shown in
Section 2.2, it has been proven that the year of construction and the
geographical location are two of the most important factors affecting
cost. For example, a decision maker that reads in a 2013 paper [37]
that the cost of water produced by a PV-RO system ranges from 11.7 to
15.6 USD/m³ may very well decide against considering that technology
as it seems very expensive. However, within the 22 year period from
1991 (from when some of the data are derived) to 2013 (when the
paper is published) the cost of PV has actually reduced by 90% [42–46].

2.2. Cost correlations

Some papers develop cost correlations (i.e. regression equations as a
function of main parameters), based on desalination project cost data-
bases. One of the important works in this category was presented in
2014 by Loutatidou et al. [47]. They performed statistical analysis of
real cost data from 950 RO plants and showed that the most important
parameters affecting the cost were:

• the plant capacity,
• the year of construction,
• the feed water salinity,
• the region where the plants are installed.

In addition, this paper [47] derived an equation that can be used to
assess the EPC costs of SWRO and BWRO plants installed in the GCC or
Southern Europe, a useful tool for decision makers that need an initial
estimation of the costs they should be expecting.

Also Wittholz et al. [48] published in 2008 a paper where a series of
cost correlations were developed for order of magnitude cost estima-
tions. Their initial database included over 500 plants and the focus was
on large scale MSF and MED plants both for seawater and for brackish
water. Finally, Lamei et al. [49] also attempted to develop a cost cor-
relation for forecasting PV-RO prices. However, their paper was based
on a database of only 21 plants of very different sizes, feed-water
qualities and energy supply arrangements, making it difficult to come-
up with a reliable correlation.

2.3. Factors affecting costs

The factors affecting the water cost have been discussed in some
papers. One such paper was published in 2013 by Ghaffour et al. [6]
and was based on an extensive review of the literature; it can be used as
a check-list when analysing the economics of desalination plants. Then,
in 2015 Ghaffour et al. [2] discussed the potential of renewable energy
driven desalination technologies, including a discussion on their costs.
It is an exhaustive paper, built on 210 references.

There are more review papers on desalination technologies, which
also touch on the issue of costs. For example Reif et al. [50] and
Bundschuh et al. [51] both in 2015 reviewed renewable energy com-
binations with thermal desalination, however the former did not go into
specific costs while the latter grouped together costs from several
sources ending up with very wide ranges that cannot be used for de-
cisions or clear conclusions.

3. Methodologies for calculating desalination costs

3.1. Investment evaluation indicators

Desalination plants involve several kinds of costs and revenues over
a long period of time during the planning, construction, operation and
decommissioning phases, which results in complicated cash flows.
There are well established methodologies applied in any kind of in-
dustry to compare different projects involving cash flows over several
years. The most commonly applied indicators used in the evaluation of
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