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# Environmental and economic performance assessment of desalination supply chain

Hasan Balfaqih [a,*], Malak T. Al-Nory [b,c], Zulkifli Mohd Nopiah [a], Nizaroyani Saibani [a]

[a] Faculty of Engineering and Built Environment, National University of Malaysia (UKM), 43600 Bangi, Selangor, Malaysia
[b] Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 03129, USA
[c] College of Engineering, Effat University, Jeddah, Saudi Arabia

HIGHLIGHTS

- Different desalination and supply chain performance measures have been reviewed.
- Delphi and AHP methods were used to develop the performance criteria and measures.
- Economic criteria include cost, revenue, leverage, profitability and water loss.
- Environmental factors are emissions, eco-toxicity potential, and employees' health.

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ABSTRACT

The interest in desalination has been growing steadily for the recent decades due to the global increased demand for fresh water. Viewing the desalination network as a supply chain permits decision makers to evaluate the performance of desalination processes end to end. However, there are few articles considered evaluating the desalination supply chain as a whole. Thus, the purpose of this study is to develop performance measurement criteria and metrics that is designed to evaluate the efficiency of desalination supply chain concerning the economic and environmental factors. Different desalination and supply chain performance measures related to economic, and environmental perspective have been reviewed. The performance measures and metrics have been further refined by a panel of experts using Delphi technique. By adopting the analytic hierarchy process technique, a weight factor has been assigned to each perspective and metric according to its significant in desalination supply chain. It is believed that both academics and practitioners would benefit from the framework developed. Finally, it must be realized that desalination is one part of the solution. Only with a synergistic approach involving desalination, water management, consumption reduction and water reuse could efficiently solve the water demand challenge in future.



## 1. Introduction

Desalination has been used since long time in the arid and semi-arid regions to match the fresh water demand. Furthermore, some countries rely completely on desalinated water for domestic and industrial needs i.e. Qatar and Kuwait [14]. However, the expansion of global population, increasing water demand, along with recent climate changes and scarceness of natural water sources have caused the increment of desalination capacity globally. The growing of desalination capacity is caused not only by the previous mentioned reasons, but also by the considerable reduction in desalination cost as an outcome of technological developments which make water desalination to be cost-competitive with other water sources [15]. Moreover, almost 50% of the world population live within 200 km of a coastline which makes seawater an accessible water resource.

The desalination plants are usually situated at coastal area in order to have an easy access of seawater. These plants have diverse desalination technologies e.g. Multi Stage Flash (MSF), Multi Effect Distillation (MED), and Reverse Osmosis (RO) with diverse production capacities which provide fresh water to coastal and non-coastal regions. The desalinated water is stored in water storage tanks then transferred to the consumers through distribution network. Such a system defines the water desalination supply chain (WDSC) [56]. Supply Chains (SC) envisage the coordination of materials, information and payments flows between individual companies to achieve competitiveness in the entire SC and ultimately to enhance the customer satisfaction [60]. It is significance to consider the economic and environmental impacts of both; treating the water by a desalination technology, and providing the desalinated water to the consumer. This allows assessing the performance of

* Corresponding author.
*E-mail addresses:* h.balfaqih@siswa.ukm.edu.my (H. Balfaqih), malnory@mit.edu, malnory@effatuniversity.edu.sa (M.T. Al-Nory), zmn@ukm.edu.my (Z.M. Nopiah), nizar@eng.ukm.my (N. Saibani).

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water desalination operations holistically [2]. For example, any delay in distributing the water from storage tanks to the consumers could cause to pause the desalination process and adversely influence the overall performance of WDSC.

The swift expansion of water desalination industry over the last decades has enhanced the need for performance measures and metrics to ensure continuous improvement of WDSC performance. This is because a process cannot be managed if its performance cannot be measured. Performance measurement can be used to report the current situation with a better understanding of the past of the process being examined and to identify future performance goals [15]. The cost of desalination SC depends on many factors such as feed water salinity, plant capacity, technology used, energy and labor costs, type of the contract, political and environmental restrictions, and distribution mains.

Technical, economic, environmental and social performance of different scales of water and sanitation supply options such as storm water recycling, grey water recycling, truck distribution [38], wastewater treatment ([11,34], desalination [37] and rainwater tank [52] were investigated in the literature employing a range of different quantitative and qualitative methods. These methods include mathematical optimization [4], multi-criteria decision analysis [38], sustainability analysis [19], specific net present value [34], and statistical analysis [52]. These quantitative and qualitative methods were applied to different case studies in developing and developed countries.

Simultaneously, the sustainability aspect and environmental impact of desalination have moved into the focus of research studies [51,49]. The aspects of energy consumption [17,44,45], and brine disposal [43] are recognized as the most relevant ones due to greenhouse gas emission and consequent global warming potential of energy generation and due to the potential effects on the marine environment of brine disposal. Few studies have considered the carbon footprint of a supply option's operational phase in their geographical scale assessment rather than a holistic environmental appraisal ([4,37,56]. While these studies have acknowledged the significance of improving water supply economic and environmental performance, there is a lack of performance measures and metrics which consider the whole WDSC. Thus, the objective of this study is to assess the economic performance and the environmental impact of WDSC by proposing related performance criteria, measures and metrics.

## 2. Background

### 2.1. Desalination

Desalination has been recognized worldwide as a feasible solution to water shortage dilemma. According to the World Health Organization (WHO), >20% of the world's population lives in regions where water is rare i.e. physical water scarcity or where the residents do not have access to water resources i.e. economic water scarcity [55]. This scarceness of natural fresh water has promoted desalination to be a main source of fresh water globally.

The desalination industry has been growing continually in the last few decades with plenty of new plants established annually. The total global capacity of desalination reached 80.9 million $m^3$/d at the end of 2013. This indicates a sharp growth since the capacity was estimated by 52.8 million $m^3$/d in 2008 and only 5 million $m^3$/d in 1980. Moreover, the total desalination market exceeds USD 31 billion in 2015 with >16,000 desalination facilities worldwide [15].

The main technologies used to produce large scale of desalinated water are MSF, MED, and RO. In MSF desalination, a heat exchanger tube heats the seawater and evaporation results from a flow of flashing brine throughout multiple stages where the vapour is condensed on the heat exchanger. The seawater is evaporated by reducing the pressure of the heated water. The energy efficiency is attained by regenerative heating as well as preheating of the incoming seawater by the condensing water vapor [12]. The MED process occurs in a series of evaporators and operates on the principle of reducing the ambient pressure in each effect. The primary steam is used to generate a secondary steam at a lower pressure which is fed to the next evaporators where the process is repeated [5].

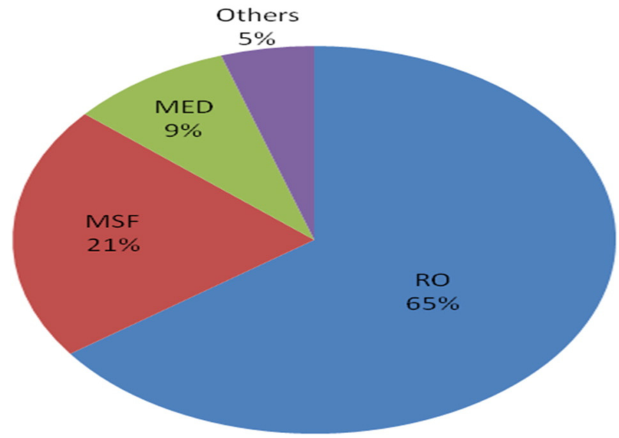


**Fig. 1.** Percentage of the worldwide installed desalination capacity by technology [20].

As it is shown in Fig. 1, >60% of the total desalination investments are for seawater RO projects due to its lower investment and due to the continuing technological advances of treating higher raw water salinities [15]. Industrial RO processes are pressure based where electric energy is used to pump the feed water through a series of semi permeable membranes. Salts are rejected from the RO membrane and hence, separation is accomplished [4].

In 2013, 65% of the worldwide installed desalination capacity was based on RO, while MSF accounts for 21% and MED for only 9% [20]. The wide application of RO desalination is due to its lower cost, lower energy demand and improved membrane durability. Freezing desalination and solar evaporation have been also developed for desalination. However, these two methods are not commercially implemented.

### 2.2. Supply chain performance measurement

A supply chain is a network of facilities and activities concerned with delivering a product from raw materials through to the customer [39]. It involves planning, and controlling material, parts and finished products distributions from the suppliers to the consumers. Performance Indicators (PIs) have been widely used as an assessment tool to transform the collected data into decision-making information through data organizing. An analysis of the difference between target vs. actual performance data can reveal the cause of mismatching supply with demand. Through using a proper approach, problems can be inspected and opportunities for development can be identified.

As a matter of a fact, there is no one best way to manage all supply chains and different supply chains have to be managed differently. This is because supply chain performance is determined by various factors which depend on the industry type and the product's characteristics [6]. Several studies proposed performance measurement frameworks for supply chain in different industries such as hospital laboratories SC [18], construction SC [53], food SC [7], dairy SC [24], furniture SC [47], Pharmaceutical SC [57], and automotive SC [16]. Despite the fact that desalination industry can benefit by applying some techniques from supply chain management, the indifferences between water desalination and manufacturing industries creates a need for specific desalination supply chain performance measures.

### 2.3. Water desalination supply chain

By looking at the water desalination process as a supply chain, it provides a comprehensive view helping decision makers to enhance the

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