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Review

Life Cycle Assessment for desalination: A review on methodology feasibility and reliability

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ABSTRACT

As concerns of natural resource depletion and environmental degradation caused by desalination increase, research studies of the environmental sustainability of desalination are growing in importance. Life Cycle Assessment (LCA) is an ISO standardized method and is widely applied to evaluate the environmental performance of desalination. This study reviews more than 30 desalination LCA studies since 2000s and identifies two major issues in need of improvement. The first is feasibility, covering three elements that support the implementation of the LCA to desalination, including accounting methods, supporting databases, and life cycle impact assessment approaches. The second is reliability, addressing three essential aspects that drive uncertainty in results, including the incompleteness of the system boundary, the unrepresentativeness of the database, and the omission of uncertainty analysis. This work can serve as a preliminary LCA reference for desalination specialists, but will also strengthen LCA as an effective method to evaluate the environment footprint of desalination alternatives.

Contents

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Nomenclature

CDI	Capacitance deionization
ED	Electrodialysis
EIO-LCA	Economic-input output life cycle assessment
ELCD	European reference Life Cycle Database
FEI	Freshwater ecosystem impact
FO	Forward osmosis
FWI	Freshwater withdrawal impact
GH	Gas hydrates
HDH	Freezing, humidification-dehumidification
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MBR	Membrane bioreactor
MED	Multiple-effect distillation
MD	Membrane distillation
MIET	Missing inventory estimation tool
MSF	Multi-stage flash
RO	Reverse osmosis
VC	Vapor compression
WEST	Water-energy sustainability tool

1. Introduction

1.1. *Desalination and associated challenges*

There are decades of successful implementations that show desalination technology can provide supplementary or even main water sources. It is estimated that the capital expenditures for new desalination plants will exceed US$17 billion by the year 2016 (Subramani et al. 2011). The desalination process can be roughly categorized into two major types: thermal and membrane separation (Van der Bruggen and Vandecasteele, 2002; Subramani et al. 2011). The thermal process mimics the natural water cycle of evaporation and condensation, and produces output water with very low salt concentration (Van der Bruggen and Vandecasteele, 2002). The membrane separation process works by prohibiting or permitting the passage of specific salts ions. Multi-stage flash (MSF), multiple-effect distillation (MED), and reverse osmosis (RO) are among the most popular technologies in thermal and membrane desalination. There are also other emerging technologies such as vapor compression (VC), electrodialysis (ED), forward osmosis (FO), membrane distillation (MD), capacitance deionization (CDI), gas hydrates (GH), freezing, humidification-dehumidification (HDH), solar stills, *etc.* (Mezher et al. 2010).

While desalination technologies are well developed, there are also some challenges that hinder broader implementation. Energy demand associated with removing salts and dissolved contaminants is far greater than treatment of freshwater by conventional water treatment processes. Desalination technologies are also subject to poor public perception related to the discharge of concentrated brine and chemical residuals (Miri and Chouikhi, 2005; Sadhwani et al. 2005; Abdul-Wahab, 2007) as well as the disposal of used membranes (Van der Bruggen and Vandecasteele, 2002; Sadhwani et al. 2005).

1.2. *Life Cycle Assessment (LCA) definition and principles*

Concerns of natural resource depletion and environmental degradation caused by desalination are motivating, the industry to investigate solutions to minimize these adverse impacts. Thus, exploring opportunities to move beyond compliance using pollution prevention strategies and environmental management systems are warranted to improve desalination technologies.

One useful tool to evaluate environmental impacts is Life Cycle Assessment (LCA). According to the ISO 14040 (ISO, 2006a), LCA is a “cradle-to-grave” approach for assessing the environmental impacts of products. Fig. 1 illustrates LCA's “cradle-to-grave” concept applied to desalination. The potential environmental burdens of desalination are attributed to the production of potable or non-potable water, which leads to the consumption of natural resources and discharge of pollutant emissions through infrastructure construction, energy generation, chemical production, membrane fabrication, and waste management.

As defined in the ISO 14040 and ISO 14044 standards (ISO, 2006a, b), LCA has four phases (Fig. 1). The “goal and scope definition” attempts to set the function unit and system boundary. The function unit describes the primary purpose of a system and enables different systems to be treated as functionally equivalent (Guinee et al. 2002). In desalination LCA studies, the functional unit is often defined as 1 m^3 of produced water. Boundary selection determines the processes and activities included in an LCA study. The determination of system boundary is often affected by factors such as the purpose of the study, geographic area affected, relevant time horizon, *etc.* (Reap et al. 2008a). “Life cycle inventory” (LCI) analysis is a methodology for estimating the consumption of resources, the quantities of waste flows and emissions caused by, or otherwise attributable to, a product's life cycle (Rebitzer et al. 2004). “Life cycle impact assessment” (LCIA)