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Life-cycle energy impacts for adapting an urban water supply system to droughts

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ABSTRACT

In recent years, cities in some water stressed regions have explored alternative water sources such as seawater desalination and potable water recycling in spite of concerns over increasing energy consumption. In this study, we evaluate the current and future life-cycle energy impacts of four alternative water supply strategies introduced during a decade-long drought in South East Queensland (SEQ), Australia. These strategies were: seawater desalination, indirect potable water recycling, network integration, and rainwater tanks. Our work highlights the energy burden of alternative water supply strategies which added approximately 24% life-cycle energy use to the existing supply system (with surface water sources) in SEQ even for a current post-drought low utilisation status. Over half of this additional life-cycle energy use was from the centralised alternative supply strategies. Rainwater tanks contributed an estimated 3% to regional water supply, but added over 10% life-cycle energy use to the existing system. In the future scenario analysis, we compare the life-cycle energy use between “Normal”, “Dry”, “High water demand” and “Design capacity” scenarios. In the “Normal” scenario, a long-term low utilisation of the desalination system and the water recycling system has greatly reduced the energy burden of these centralised strategies to only 13%. In contrast, higher utilisation in the unlikely “Dry” and “Design capacity” scenarios add 86% and 140% to life-cycle energy use of the existing system respectively. In the “High water demand” scenario, a 20% increase in per capita water use over 20 years “consumes” more energy than is used by the four alternative strategies in the “Normal” scenario. This research provides insight for developing more realistic long-term scenarios to evaluate and compare life-cycle energy impacts of drought-adaptation infrastructure and regional decentralised water sources. Scenario building for life-cycle assessments of water supply systems should consider i) climate variability and, therefore, infrastructure utilisation rate, ii) potential under-utilisation for both installed centralised and decentralised sources, and iii) the potential energy penalty for operating infrastructure well below its design capacity (e.g., the operational energy intensity of the desalination system is three times higher at low utilisation rates). This study illustrates that evaluating the life-cycle energy use and intensity of these type of supply sources without considering their realistic long-term operating scenario(s) can potentially distort and overemphasise their energy implications. To other water stressed regions, this work shows that managing long-term water demand is also important, in addition to acknowledging the energy-intensive nature of some alternative water sources.

1. Introduction

Many regions have faced serious water stress in recent years, including southeast Australia (Van Dijk et al., 2013) and southwest United States (Prein et al., 2016). Some cities in these regions

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explored and introduced alternative water sources to cope with their water crises (Aghakouchak et al., 2014). These water sources include seawater desalination, potable water recycling, inter-basin water transfers, and decentralised water sources. Most new sources are more energy intensive than conventional water sources (Rothausen and Conway, 2011; Wakeel et al., 2016), and have significantly increased the long-term energy footprint of some water supply systems (Lam et al., 2016; Li et al., 2016).

South East Queensland (SEQ) in Australia, for example, experienced a decade-long drought, known as the Millennium Drought (Van Dijk et al., 2013). The drought was most profound between 2001 and 2009 with the average annual inflow to the major reservoirs less than 20% of the long-term average (Water Services Association of Australia, 2013). A wide range of supply-side and demand-side responses were used to cope with the drought (Head, 2014). On the supply-side, there were four major strategies – i) building a seawater desalination plant, ii) constructing an indirect potable water recycling system, iii) connecting four distinct water supply networks with three bulk water transfer pipelines, and iv) promoting a large-scale uptake of residential rainwater tanks. On the demand-side, strategies such as outdoor water restrictions, water-efficient appliance rebate programs and water conservation educational campaigns were employed.

Prior research in SEQ has examined the energy impacts of some of these supply-side changes. Poussade et al. (2011) quantified the life-cycle energy impact of some parts of the newly commissioned desalination system and indirect potable water recycling system. Hall et al. (2011) performed a future scenario analysis based on a water strategy set out during the drought. Lane et al. (2015) conducted a detailed life-cycle assessment of a subset of the SEQ urban water system. These studies were based on empirical data and information available during the drought. More recently, Kenway et al. (2015) conducted a systemic analysis of water-related energy use in SEQ and Lam et al. (2016) quantified the direct energy use of the SEQ's water supply system through and after the drought.

Building on these earlier efforts, this paper addresses two gaps in literature concerning life-cycle energy implications of alternative water sources based on the post-drought SEQ context and new empirical data. First, previous studies typically defined and compared scenarios assuming a high utilisation of specific alternative water sources (Hall et al., 2011; Lane et al., 2015; Lundie et al., 2004; Mo et al., 2014; Shrestha et al., 2011), not accounting for possible influence of climate/water variability on operations over a long assessment period. While an “upper bound” scenario can capture the maximum impact of using a specific alternative water source, more realistic scenarios should also be evaluated to understand the more likely long-term energy impacts on urban water systems. For instance, most new desalination plants in Spain were idle as of 2012 (March et al., 2014) and only two out of the six desalination plants built in Australia during or shortly after the drought were still in high utilisation as of 2016 (Turner et al., 2016).

Further, limited research has been conducted on regional life-cycle energy impacts of a large-scale uptake of rainwater tanks. Previous studies focused predominantly on evaluating single rainwater harvesting systems (Cook et al., 2013; Devkota et al., 2013; Racoviceanu and Karney, 2010) without examining how these individual results would scale in a regional evaluation. In addition, few studies compare the regional life-cycle energy use of decentralised systems (i.e., typically rainwater harvesting in SEQ) with that of the centralised systems. It is important to understand how much they can contribute to the overall energy use of urban water supply systems. Decentralised systems have gained popularity in recent years and a number of empirical studies have found that rainwater harvesting systems are more energy intensive than conventional centralised water supply systems, e.g., (Vieira et al., 2014). The rapid implementation of rainwater harvesting in SEQ provides a wealth of empirical data to explore these two aspects.

This work presents a life-cycle energy assessment of the urban water supply system in SEQ. The goal is to assess the relative life-cycle energy impacts of the four alternative water supply strategies introduced during the drought. Current post-drought and future energy impacts of the strategies under various utilisation and water demand scenarios are quantified. This study provides insight for developing more realistic scenarios to evaluate the life-cycle energy impacts of drought-adaptation centralised water supply sources and regional decentralised water sources. The discussion focusing on the experience in SEQ is highly relevant to other water-stressed regions where they may be exploring future alternative water supply strategies to cope with supply constraints (e.g., drought) or increasing water demand.

2. Case study background

South East Queensland (SEQ), where the Queensland state capital Brisbane is situated, is an urbanised region on the eastern coast of Australia. It has more than 60% of the state's population. Its traditional water source is surface water from major reservoirs such as Lake Wivenhoe, Lake Samsonvale and Advancetown Lake. Its water supply system was designed to have a high carry-over capacity (i.e., the total storage capacity was estimated to be over six times the annual urban water demand (Marsden and Pickering, 2006)). Between 2001 and 2009, the region experienced its longest recorded continuous period with below average rainfall (more than 80% lower than the long-term average). The unprecedented low catchment inflows led to a water crisis. These pre-drought surface water supplies are referred to as the conventional supplies. In response to the drought, four water-supply strategies were introduced to the regional water supply systems to augment the supply (Turner et al., 2016).

Firstly, three bi-directional bulk water transfer pipelines were built to connect four previously segregated water supply networks. The Southern Regional Water Pipeline connects the Greater Brisbane system to the Gold Coast system; the Northern Pipeline Interconnector connects the Greater Brisbane system to the Sunshine Coast system; and the Eastern Pipeline Interconnector connects the Brisbane-Logan system to the Redland system. Forming a bulk water supply network improved regional water supply flexibility and was estimated to increase the overall regional water supply system yield by 14% compared to the pre-drought system prior to integration (Queensland Water Commission, 2010).

Secondly, a 125 ML/day capacity reverse osmosis seawater desalination plant (the Gold Coast Desalination Plant) and a 25 km product water pipeline were built. The potable effluent is fed into the Gold Coast system and can be transferred to the other parts of the SEQ system through the newly-built Southern Regional Water Pipeline. In 2010, the desalination system had the potential to increase the system yield by approximately 9% (Queensland Water Commission, 2010).

Thirdly, a 232 ML/day capacity indirect potable water recycling system (the Western Corridor Recycled Water Scheme) was built. The system includes three advanced wastewater treatment plants and over 200 km of bulk water pipelines. The system provides recycled water treated to potable water quality standards, well beyond what is necessary for the cooling purposes, to two major power plants in the region which were drawing water from drinking water supplies during the drought. It also can feed the highly-treated potable recycled water into Lake Wivenhoe (the major reservoir in SEQ). However, due to easing of the drought and political pressure, this indirect potable water use option has not been implemented. In 2010, the water recycling system had the