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Understanding the future of Seawater Air Conditioning in the Caribbean: A simulation approach

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ABSTRACT

Seawater Air Conditioning (SWAC) is a sustainable alternative for tropical islands. Despite its potential, adoption has been limited throughout the world. There is a need to understand SWAC adoption potential in the Caribbean and to identify the actions and policies that could favor its diffusion. We develop a system dynamics simulation model for SWAC adoption, and use it to simulate scenarios and incentives for SWAC in Jamaica. We found that SWAC adoption is mainly limited by the threshold capacity necessary for the first installation. To achieve full adoption by 2050, governments and investors should finance 100% of the first pipeline before 2020.

1. Introduction

Over the past two decades there has been growing pressure to reduce emissions and the use of fossil fuels, particularly for generating electricity. This has led to an increase in the use of renewable energy sources, especially wind and photovoltaic, thereby mitigating climate change. The ocean is the largest energy reservoir and offers alternative methods for power generation such as tidal, thermal gradient, saline gradient and wave energy (Pelc and Fujita, 2002). Nevertheless, ocean renewable energy technologies still play a minor role in the global energy mix, with only 530 MW installed out of a total global capacity of about 5600 TW (IRENA, 2014). While many of these technologies are still not fully commercialized, they have great potential to contribute to the future energy mix without contributing to global warming. They also provide new ways of substituting electricity or at least significantly reducing consumption in certain circumstances. The model developed and discussed here demonstrates that under the right conditions, the use of seawater for air conditioning (AC) can be advantageous.

In 2010 global energy consumption for cooling was 1.25 PWh, which was 9.6% of total global energy consumption; 35% of this was consumed in the Americas (Santamouris, 2016). Consumption is significantly higher in tropical countries where cooling is often used year-round. In Townsville, Australia, cooling accounts for 28% of electricity demand in the residential sector (Ren et al., 2013), while in Hong Kong this figure is 23% in the residential sector and 26% in the commercial sector. This is equivalent to 15.8% of the city's total electricity consumption (Jim, 2015). In the Caribbean, AC can account for up to 40% of the electricity demand of the hotel industry (CTO, 2016) and 16% of total electricity consumption on a given island.

Climate change, population growth and economic growth are the main drivers of AC demand. Global AC demand is therefore expected to increase by 35% in the residential sector and 67% in the commercial sector by 2050 (Santamouris, 2016). AC could increase the effect of heat islands in cities and increase temperatures by up to 1 °C, which in turn increases the demand for cooling (Salamanca et al., 2014).

This paper is organized as follows. We begin by providing an overview of Seawater Air Conditioning technology, followed by a review of several energy diffusion models to illustrate how renewable energy technologies spread. We then develop a simulation model of the adoption of the technology on a Caribbean island and use this model to understand the effects of different policies on the adoption of the technology. Finally, we discuss the results and the contribution made by the paper.

2. Seawater Air Conditioning (SWAC)

The traditional AC systems used in buildings in the Caribbean range from single mini-split systems (to provide AC for rooms) to variable refrigerant flow systems (centralized AC for entire buildings). Although there are differences in cost and efficiency, all systems use the same main principle to operate (see Fig. 1), with negative impacts on the environment, mainly due to refrigerant leaks (ozone depleting substances), thermal pollution through the release of hot air and high electricity consumption. On top of this, in the Caribbean 95% of this electricity comes from fossil fuels (IRENA, 2012).

SWAC systems, or Seawater District Cooling systems, are a

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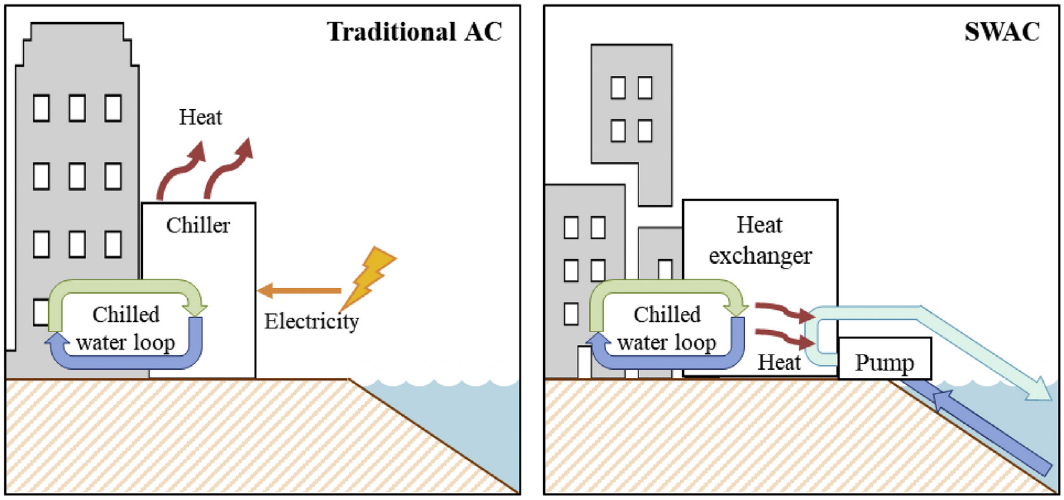

Fig. 1. Comparison of the main components of traditional AC and SWAC. Based on (CAF and Makai, 2015).

renewable energy technology that uses cold deep ocean water (DOW) for cooling cities or communities near a DOW source (see Fig. 1). In a SWAC system cold water is pumped from its source (sea or lake) into a cooling station, and used to chill freshwater. The cold freshwater can then be distributed to the final users and cool the air in buildings. The process finishes either with the return of the seawater to the ocean or its use for other applications.

SWAC has several advantages when compared to traditional AC. Firstly, SWAC districts could save up to 90% of the energy used in a traditional system with the same capacity (Looney and Oney, 2007). Some studies estimate that AC accounts for approximately 50% of the peak installed capacity in tropical cities (Chua et al., 2013; Edwards et al., 2012), but this capacity is only reached during the hottest hours of the day. SWAC implementation could therefore be of benefit to local electricity grids by flattening the demand curve (Chua et al., 2013). Secondly, SWAC also reduces the GHG emissions responsible for climate change, eliminates the environmental impacts of heat release and removes the risk of refrigerant leaks (Makai, 2011). Finally, SWAC systems can have lower operational costs and a lower levelized cost of energy (LCOE) compared to traditional systems, given that most operational costs of traditional AC result from electricity consumption (Looney and Oney, 2007).

It is expected that SWAC could be a better alternative to traditional AC in some cases, both environmentally and economically; however, its application remains limited. Large-scale plants (> 3000 tons) using lake water currently operate in Toronto, New York, Amsterdam and Stockholm, to name a few. The use of seawater is limited to small-scale operations (pilots or single-building plants under 300 tons) in Hawaii, Japan and Korea, with projects in the design stage in Honolulu, the Bahamas, Réunion and Curacao (Osorio et al., 2016). The major challenges for SWAC are the high investment costs compared to traditional AC (Looney and Oney, 2007) and a lack of knowledge regarding environmental impacts on ocean ecosystems (Lilley et al., 2015).

3. Diffusion models for energy policy

The diffusion of new products or technologies is usually modeled as a logistic curve with an S-shaped behavioral pattern (Sterman, 2000). This has been applied to the introduction of new products in a market, from toothpaste to energy technologies (Arias-Gaviria et al., 2017). This S-shaped behavior represents the cumulative capacity of the adopted technology and explains how the adoption rate is slow in the initial stages and then increases until the market is saturated and adoption ceases (Rao and Kishore, 2010). Bass (1969) proposed the first diffusion model where the adoption rate was a function of two coefficients, one representing the innovative adopters and the other representing the imitators. The model was later generalized to include costs and profitability of the technology as factors influencing the decision to adopt (Bass, 2004).

Methodologies used in modeling the adoption of renewable energy have evolved from econometric estimations in the early 2000s to system dynamics (SD) and agent-based models (ABM). Some examples include Masini and Frankl (2002), who used an econometric estimation of a logistic model to evaluate different policies for the diffusion of solar PV in Europe. Similarly, Lund (2006) and Söderholm and Klaassen (2007) estimate logistic functions for analyzing the diffusion of different RE technologies in the same region. Purohit and Kandpal (2005) also use econometric estimations for performing a cross model analysis of five diffusion models (Bass, Gompertz, logistic and Pearl) applied to the adoption of RE for water pumping in India. In a more recent study with econometric estimations, Popp et al. (2011) evaluate patents for wind, solar, geothermal and biomass in OECD countries as a knowledge bank for technology penetration. System dynamics applications for RE diffusion include evaluation of incentives for wind energy worldwide (Alishahi et al., 2012), RE from different sources in Colombia (Arias-Gaviria et al., 2018; Cardenas et al., 2016; Zuluaga and Dyner, 2007), distributed generation in Colombia (Carvajal et al., 2011), biomass in Greece (Toka et al., 2014) and others. ABM have been used more recently and to a greater extent in the diffusion of RE for several applications. Some studies consider a consumer choice model to be a basic theory and apply it to competition among micro-cogeneration technologies in the Netherlands (Faber et al., 2010), plug hybrid vehicles (Eppstein et al., 2011), dynamic electricity tariff adoption (Kowalska-Pyzalska et al., 2014), renewable heating systems (Sopha et al., 2013) and rooftop solar PV adoption (Murakami, 2014; Palmer et al., 2015).

On the topic of socio-environmental system modeling, the literature unanimously affirms that the choice of the modeling methodology initially depends on the research problem and the purpose of the model (see, for example, Davis et al., 2007; Kelly (Letcher) et al., 2013; Pidd, 2004; Sterman, 2000). Thinking, decision-making or soft modeling tools (such as DS or ABM) are preferred when the research problem involves human behavior, a lack of knowledge of the system, a lack of data and has no analytical solution (Pidd, 1999), and when the purpose of the model is to learn and understand rather than predict (Kelly (Letcher) et al., 2013).

In sum, diffusion models have been widely applied to RE for three main purposes: policy evaluation, describing and understanding behavior, and prediction. The selection of the modeling approach depends