Resources, Conservation and Recycling 98 (2015) 76–84

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Virtual water management and the water–energy nexus: A case study of three Mid-Atlantic states

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ARTICLE INFO

Article history:
Received 18 August 2014
Received in revised form 16 January 2015
Accepted 17 January 2015

Keywords:
Water–energy nexus
Water for energy
Virtual water imports
Water inequity
Electricity trading
Sustainable energy scenario

ABSTRACT

Virtual water imports arise when electricity and input fuel imports for electricity generation are expressed in terms of the quantity of water consumption not fully accounted for through pricing of imported electricity and input fuels. Such incomplete accounting means that electricity and input fuel exporters and other stakeholders suffer an unequal share of the net costs, including negative local ecological impacts. This paper utilizes the term "water inequity" to capture this phenomenon. It does not argue against electricity and/or input fuel trading, but focuses on the need to reduce regional water inequity by lowering virtual water imports through sustainable electricity policies. Under unchecked business-as-usual (BAU) trends, water inequity attributable to virtual water imports by the three case study states (Delaware, Maryland and New Jersey) could reach 420.2 million m^3 by 2025, which would be 39% higher than total in-state water consumption for electricity generation. These states are already deploying sustainable energy-focused policy tools, including Energy Efficiency Resource Standards (EERS) and Renewable Portfolio Standards (RPS). This research demonstrates, by means of sustainable energy scenario analysis, that EERS combined with RPS can reduce water inequity by an average of 35% in the states under review, ranging from 34% (Maryland) and 35% (Delaware) to 37% (New Jersey). This will enhance sustainability in terms of energy, environment, economy and equity (E^4) for both importing and exporting states. This paper concludes by offering policy options to maximize the synergistic benefits of virtual water inequity reduction.

1. Introduction

Societies across the globe are experiencing increased water and energy vulnerabilities at local, regional and national scales. Some argue that the world will face two crises in the 21st century: a water crisis and an energy crisis (Brown, 1998; Flavin, 1999; Feffer, 2008). A crisis of water scarcity, reflected in falling water tables attributable to over-consumption, is being amplified by threats to water quality as contamination increases. Water security has been identified by some as the single most important factor regarding the future sustainability of our planet (Biggs et al., 2013). The current conventional energy system, dominated by fossil fuels and nuclear power, is also increasingly vulnerable, especially due to major climate trends such as decreasing water availability, increasing intensity and frequency of storm and flooding, and sea level rise (DOE, 2013; Forster and Lilliestam, 2010). To mitigate climate change, proper alternative energy technologies that significantly lower water consumption and lower carbon emissions need to be deployed (Pittock, 2011). If society does not improve its management of energy and water resources in a timely manner, we will damage the ability of future generations to meet their needs.

Given this context, there is a need for greater understanding of energy–water linkages in order to develop more effective policies to address cross-vulnerabilities (Hussey and Pittock, 2012). Approaches to resolve this issue must recognize, embrace and exploit the synergies that exist between these two sectors. The interdependence between water and energy can be collectively classified as the water–energy nexus: producing and distributing energy requires water, and supplying and consuming water

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http://dx.doi.org/10.1016/j.resconrec.2015.01.005

requires energy (Ackerman and Fisher, 2013; Siddiqi and Anadon, 2011; Schramm, 2013). Scott et al. (2011) conclude that "despite the operational interdependencies between water and energy, there are few examples of tandem management of both resources" (p. 6622).

Following the U.S. Energy Policy Act of 2005, the U.S. Department of Energy's (DOE) national laboratories and the Electric Power Research Institute (EPRI) initiated a multi-year water–energy program that included R&D and outreach which was expected to cost $30 million annually through 2009. Prior to this initiative, there was hardly any U.S. government support for water–energy nexus issues on the national agenda. More recently, the Energy and Water Research Integration Act of 2009 (introduced as Senate bill 531) aimed to ensure consideration of water intensity in the Department of Energy's energy research, development and demonstration programs to help guarantee efficient, reliable and sustainable delivery of energy and clean water resources. Although this bill was not passed into law it represented an "important national step towards energy–water policy coupling" (Scott et al., 2011: p. 6623).

An important driver of the water–energy nexus is the realization that water withdrawal by electric power plants has more than quadrupled in a little over 50 years: 40 billion gallons per day in 1950 to 201 billion gallons per day in 2005 (Kenny et al., 2009). The largest withdrawal of water in the United States in 2005 was for use by thermoelectric power plants (49%), followed by irrigation (31%) and public and other water users (20%) (Kenny et al., 2009). Most thermoelectric power plants are fueled by coal, nuclear energy and natural gas, with coal power plants accounting for about 37% of the total electricity produced in the United States in 2012, natural gas 30% and nuclear energy 19% (EIA, 2012a). According to EIA (2011), thermoelectric generation will account for 85% of total electricity generation by 2035.

The upsurge of interest in water withdrawal is paralleled by increasing attention to the phenomenon of "embedded" or "virtual water" transfers that occur in the process of electricity and energy trading between states or regions. The notion of virtual water – water embedded in energy in our case (ACEEE, 2011) – has been captured extensively in several studies (Verma et al., 2009; Galan-del-Castillo and Velazquez, 2010; Velázquez et al., 2010; Novotny, 2013). Some scholars that focus on agriculture highlight the benefits of treating virtual water as a tradable commodity that can be exchanged between states and/or regions, thereby enhancing overall economic efficiency in water resource use (Qadir et al., 2003; Chapagain and Hoekstra, 2004; Wichelns, 2004; Dabrowski, 2014). This paper examines another dimension of virtual water by highlighting the equity implications (referred to as "water equity") resulting from inter-state or inter-regional electricity and fuel trading that have not previously been addressed.

In the sections which follow we first address the water–energy nexus concept, focusing on "water for energy" "virtual water" and "water inequity." After this we introduce the three case states covered by this study, namely, Delaware, New Jersey and Maryland. This is followed by an evaluation of water inequity in the PJM regions and beyond in the reference year of 2010 by three case states. Next, we perform a scenario analysis with a target year of 2025 and evaluate the potential for reduction in water inequity that might be realized in the context of an alternative sustainable energy scenario (SES); one in which Renewable Portfolio Standard (RPS) and Energy Efficiency Resources Standard (EERS) are assumed to be fully implemented by 2025. This reduction is compared with the 2025 Business-as-Usual Scenario (BAU-2025) and the reference year of 2010. The same approach is applied to reduction of in-state water consumption associated with electricity generation in 2025. In the final section we offer policy suggestions and conclusions.

2. Major concepts

2.1. Water–energy nexus: focusing on water for energy

At the core of the water–energy nexus is the demand of water for energy and demand of energy for water (Gleick, 1994; Rio Carrillo and Frei, 2009; Siddiqi and Anadon, 2011). Energy for water is an important topic (Sudeep et al., 2014), but our focus is on water required for energy. The extraction and preparation of input fuels for electricity generation consumes significant quantities of water and impacts water quality. According to the U.S. DOE (2006), coal mining is estimated to consume approximately 1–6 gallons per million Btu (MMBtu), while also impacting local water quality. The typical petroleum refinery consumes 7–18 gallons per MMBtu (DOE, 2006). The production of oil from tar sands and natural gas from shale gas also consumes a significant amount of water. Oil extracted from shale requires 15–28 gallons per million Btu (MMBtu), and oil sands require 20–50 gallons per MMBtu (DOE, 2006). The U.S. EIA noted that natural gas will account for 60% of electricity generation capacity additions between 2011 and 2035, and shale gas is anticipated to drive this growth (EIA, 2012b).

The use of open-loop cooling systems by power plants often draws aquatic wildlife into the system, and aquatic environments are further endangered when warmer water is returned into the surrounding ecosystem (Gagnon-Turcotte and Pebblesa, 2009). Closed-loop cooling systems withdraw less water and endanger aquatic wildlife to a lesser degree compared to open-loop cooling systems, but the systems consume more water since water is not directly returned from where it came (Macknick et al., 2011). Dry cooling systems withdraw and consume minimal water, but they have a high capital cost and have less overall power plant efficiency compared to closed-loop cooling systems (Gagnon-Turcotte and Pebblesa, 2009).

Given the amount of water required for thermolectric use, this paper concurs with Sovacool and Sovacool (2009), who noted the precarious nature of electricity generation given the likelihood of future droughts and water shortages, especially during the summer months. For example, the U.S. Geological Survey (USGS) predicted that almost a quarter of the United States will encounter severe droughts by 2040, with states in the West expected to suffer the most (Smith et al., 2014).

In contrast to their conventional counterparts, renewable energy technologies such as solar photovoltaic systems and wind turbines require no cooling water and only minimal water for washing the panels and cleaning blades, respectively. Hydroelectricity generation also does not require water for cooling, but high volumes of water are consumed via evaporation losses from the surface of reservoirs and dams. Additionally, temperatures are altered, and ecosystems are radically altered up and downstream (Torcellini et al., 2003). Water consumption by other renewable technologies varies substantially. For example, concentrated solar power (CSP) plants require more cooling water per unit of electricity generated compared to fossil and nuclear plants since CSP plants operate at lower temperatures with less steam efficiency (Carter and Campbell, 2009). Geothermal power plants make use of convective hydrothermal resources inside hot rock beds. However, external water supplies are usually required given that many geothermal resources do not naturally contain enough water (Clark et al., 2010).

2.2. Virtual water trading and water inequity

Virtual water is a measure of how much water is embedded in the production and distribution of a good or service (Hoekstra and Hung, 2002; Galan-del-Castillo and Velazquez, 2010; Velázquez et al., 2010). The concept is well established in agricultural