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The development of an integrated model for the assessment of water and GHG footprints for the power generation sector

Nikhil Agrawal, Md Ahiduzzaman, Amit Kumar*

University of Alberta, Department of Mechanical Engineering, 10-263 Donadeo Innovation Centre for Engineering, Edmonton, Alberta T6G 1H9, Canada

HIGHLIGHTS

- Assessed long term impacts of climate change on water consumption and GHG emissions.
- Evaluated cost effectiveness of various scenarios by developing water-carbon cost curve.
- Developed models in LEAP and WEAP that include demand tree, reference scenario.
- Coal to gas conversion will save water, reduce emissions while being cost-effective.
- Framework will help policy makers in other regions to develop climate change strategies.

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ABSTRACT

To ensure the use of water today does not damage the prospects for its use by future generations, there is need to understand long-term water demand and supply through energy production, conversion, and use. This study aims to develop an integrated framework to assess the long-term impacts of climate change scenarios on water requirements and greenhouse gas (GHG) emissions. The framework includes the integration of the Water Evaluation And Planning model (WEAP) and the Long-range Energy Alternative Planning Systems model (LEAP). As many countries are planning to move towards a cleaner electricity grid to mitigate climate change, this work attempts to present the impact of various scenarios on water demand, GHG emissions, and cost effectiveness. This is done by conducting a case study of the western Canadian province of Alberta where more than 85% of electricity is generated by fossil fuels. This paper provides a comprehensive overview of nine integrated LEAP-WEAP climate change scenarios for the years 2015–2050 by forecasting water consumption and greenhouse gas emissions from the power sector. The economic aspects of the developed scenarios are discussed in the form of a cost curve that shows the GHG saving potential, water use, and GHG mitigation costs for each scenario. For the Business-As-Usual (BAU) scenario (coal power phase out by 2030), GHG emissions and water demand will fall by 44% and 34%, respectively, in 2030. The integrated results show that the scenarios will mitigate carbon emissions but will result in higher water consumption, which will directly affect water resources in the region. Because of the high investment cost to install the considered renewable power plants in the climate change scenarios, the cost of mitigating carbon emissions in the power sector is high. Early coal-to-gas power plant conversion is the only scenario that is expected to save water (67 million m^3) and reduce emissions (40 million tonnes of CO_2 eq.) and be cost effective ($68/tonne of CO_2 eq.). These LEAP-WEAP model results can help create awareness among policy makers to understand the water-energy demand and supply relationship in a quantifiable way.

1. Introduction

Over the last two centuries, water management connection with energy has been deepened due to development of complex and resource intensive societies. Energy and water are valuable resources that support human prosperity and are interdependent (for power generation,

Abbreviations: AESO, Alberta Electric System Operator; AUC, Alberta Utilities Commission; BAU, Business-As-Usual; BCM, Billion Cubic Meters; CANSIM, Canadian Socio-Economic Information Management System; CLP, Climate Leadership Plan; CO_x, carbon oxides; GHG, Greenhouse Gases; GWh, Gigawatt Hour; HDI, Human Development Index; IPCC, Intergovernmental Panel on Climate Change; LEAP, Long-range Energy Alternatives Planning system; MWh, Megawatt Hour; NEB, National Energy Board; NGL, Natural Gas Liquids; NPV, Net Present Value; SO_x, sulphur oxides; TED, Technology & Environment Database; UNDP, United Nations Development Program; WEAP, Water Evaluation And Planning

* Corresponding author.
E-mail address: Amit.Kumar@ualberta.ca (A. Kumar).

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extraction, transport and processing of fossil fuels) [1,2]. Water and energy have a symbiotic relationship. Energy is needed for wastewater treatment, drinking water treatment, transmission and distribution of water, and water is needed for fuel production such as ethanol, hydrogen, extraction and refining, thermoelectric cooling and hydropower production. When discussing about water use and sectoral demand, it is important to distinguish between water withdrawal and water consumption. Water withdrawal (or water demand) represents the total water taken from a source (i.e. water body the water is withdrawn from), while water consumption represents the total amount withdrawal that is not returned to the source [3–5].

Water withdrawals for energy production globally in 2010 were estimated at 583 billion cubic meters (BCM) (15% of world's total water withdrawals) [6]. Of this withdrawal, 66 billion cubic meters is the water consumption – volume withdrawn but not returned to its source [6]. In United States in 2010, as estimated by United States Geographical Survey (USGS), about 41% of nation's available water was withdrawn by thermoelectric power plants [7]. In the energy sector, water requirement for fossil fuel-based and nuclear power plants are the largest.

Fig. 1 shows projection for global primary energy production and global water use for energy production which shows a 48% increase in energy consumption from 2010 to 2040 which translates to a 42% increase in water consumption [6,8]. Key drivers behind this increase in energy use and water consumption are population growth and increase in income per person. A chart developed by United Nations Development Program (UNDP) shows a direct correlation between electricity use per capita and quality of life, i.e., human development index (HDI) [9]. So, as we are aiming to improve our quality of life globally, we will be increasing our energy use. Currently, we rely primarily on fossil fuels which are increasing the global warming. So, one of our biggest challenges is to maintain an improving quality of life while decreasing the emissions from fossil fuels (mitigating climate change). Some options to mitigate global warming are:

- Reducing the greenhouse gases (GHG) through decrease in our energy use which can be achieved either by consuming less energy or using energy efficient equipment.
- Increasing our clean energy supply with renewables [10–13].

This study focuses on the later part i.e. increasing our clean energy supply with renewables. Further, under climate change mitigation, role of electricity generation mix is becoming more prominent, resulting in increased water demand for power plant cooling purposes [14]. This study focuses on water use for energy production primarily in electricity generation sector. A combination of technologies such as nuclear, fossils or biomass with carbon capture and storage and renewable sources characterized by diverse water requirements are the means for achieving decarbonization of electricity systems thus impacting the water resources [15–17].

Following the Paris climate change conference, one of the major

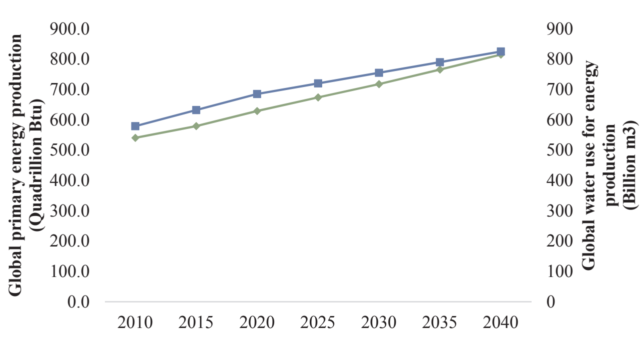

Fig. 1. Energy production and water consumption projection (2010–2040) [6,8].

outcomes is mitigating Greenhouse gases (GHG) emissions [18]. In electricity generation sector, coal generation pathway is the main source of carbon emissions. This study presents a case study of western Canadian province, Alberta, where more than 85% of electricity is generated by fossil fuels. Alberta is responsible for 65% of Canada's coal-fired electricity generation [19]. So, the success of Canada's move away from coal will be judged by Alberta's transition from coal to renewables. Also, Alberta has been the highest GHG emitter in the country since 2005 with 273 million tonnes of carbon emissions (out of 732 million tonnes) in 2014 [20]. In November 2015, Alberta government announced Climate Leadership Plan (CLP) which outlines the province's proposal to curb its emissions [21]. One of the key strategy outlined in the report is to end coal pollution by phasing out province's coal-fired power plants by 2030. Hence, Alberta's electricity generation sector is currently at an inflection point and a successful transition to cleaner sources of energy will set a guideline to upcoming states and countries for their transition. In Alberta, with the expected shift towards greener electricity grid (as highlighted in the Government of Alberta Climate Leadership Plan), it is critical to understand the impact of climate change mitigation efforts on water demand. Water use and consumption for the electricity generation sector will be highly influenced by proposed air emissions regulations and technology advancement to improve water intensity in power sector [22].

To make well informed long-term decisions, policy makers and resource managers need to fully understand the interconnections between energy production and water use, or water-energy nexus [23]. Planning and assessment issues require strategies to minimize the vulnerabilities around water and energy while mitigating the corresponding GHG emissions. Some studies on water energy nexus have been conducted in the past and a summary of literature review focused on water use and electricity production is described below.

Some of the papers discuss the impact of climate change mitigation scenarios on water demand or on energy sector indirectly affecting water demand. Climate change can impact energy sector (both demand and supply) in a number of ways such as changes in the efficiency of power plants, increased rainfall may enhance hydroelectricity output, but thermoelectric power may become vulnerable due to higher temperature and increases in peak demand due to higher cooling demand in hotter summers [24,25]. Climate change mitigation scenarios include adoption of renewable technologies like wind, hydropower, solar, carbon capture & storage, reduction of fossil fuel based power plants, etc. Mouratiadou et al. [26] present an integrated assessment model of water-energy-land-climate to assess the changes in electricity and land use, induced by climate change mitigation, impact on water demand under alternative socioeconomic and water policy assumptions. Nanduri and Otieno [27] propose a framework of a joint carbon and water cap-and-trade model to understand implications of electricity-water-climate change nexus and present a multi-agent reinforcement learning-based predictive model. Ciscar and Dowling [28] in 2014 presented a review on how integrated assessment models have estimated impacts of climate impacts and adaptation in the energy sector concluding that there is vast amount of work that needs to be done in order to understand the vulnerability of energy sector stating the fact that most important aspect is the adaptation options available in energy sector, their costs, effectiveness and potential. Water-energy nexus for Middle East and North Africa region was reviewed by Siddiqui and Anadon [29] which highlighted a weak dependence of energy systems on freshwater, but a strong dependence of water extraction and production on energy. Most of the Arabian Gulf countries consume 5–12% of the total electricity consumed for water desalination. Based on these studies, it can be summarized that research focused on integrated GHG and water footprints for energy pathways are limited. A big challenge as discussed by Sovacool and Sovacool [30] is to improve quality of research related to electricity-water issues. Currently, there are limited studies available that correlates water demand, greenhouse gas emissions and cost effectiveness of scenarios for an energy sector over long-term planning