



Integrating water and energy models for policy driven applications. A review of contemporary work and recommendations for future developments



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ABSTRACT

Availability of and access to water and energy are key ingredients for economic and social development. Unfortunately, more than a billion people still lack access to both safe freshwater and basic energy services. Future predictions show that the situation may become worse with about a 40% increase in energy demand and 30% increase in water demand by 2040. In addition, water and energy are highly interdependent, with water needed in all phases of the energy lifecycle and energy needed in all phases of the water lifecycle. While recent years have seen an increasing number of studies on the water-energy nexus, the research is focused on scattered individual areas of the nexus, each important in their own right. However, there is now a need to synthesize these efforts and identify the most important elements needed for a holistic water-energy nexus methodology. This paper focuses on the benefits to be gained from and the drawbacks of ignoring various water-energy interlinks for policy makers and planners in their goals to meet long term resource security. Several possible combinations of socio-economic and climate change scenarios make these goals even more challenging. The lessons learnt from reviewing different integration methodologies and studies are compiled into a list of key recommendations. It is found that current integration efforts are often biased towards the energy sector and its water requirements. There is still a need for better representations of the water infrastructure and corresponding linkages with the energy sector. There is also a need to harmonize the energy and water systems from both a technical and policy perspective. This calls for compatible disaggregation of spatial and temporal elements in both systems as well as designing model outputs to allow evaluation of the synergies and tradeoffs of multi-scale, cross-sector policies.

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1. Introduction

This paper investigates water and energy resource planning models designed to aid government departments, planners and policy makers to plan, manage and provide the relevant services needed to reach a desired level of quality of life. While quality of life can be a relative term, most definitions and indicators (e.g. United Nations (UN) Human Development Index [1], UN Millennium Development Goals [2], World Bank World Development Indicators [3], UN Sustainable Development Goals [4]) include improved access to health and sanitation services, a steady reliable source of food, improved economic and industrial activity and sufficient infrastructure to facilitate implementation and operation. These goals are sought keeping in mind multiple constraints including costs, environmental impacts, international policies and other political motivations. While, there are many elements involved, water and energy are two of the key common resources shared between almost all of these activities. Up until a few decades ago, with abundant supplies relative to demands, the management and infrastructure of the two sectors evolved independently, encouraging delineated responsibility and sector-specific planning [5].

However, both systems are becoming increasingly strained as a result of rising total demand due to population growth; increased per capita consumption due to economic and lifestyle changes; and climate change impacts on demand and availability patterns [6]. At least 1.8 billion people still lack reliable access to water safe for human consumption and about 2.4 billion lack improved sanitation facilities [7]. About 1.2 billion people also still lack access to electricity and about 2.7 billion still cook using solid fuels [8] leading to nearly 2 million deaths annually [9].

The future is very uncertain with several possible socio-economic development pathways, simultaneously framing and shaped by several climate change scenarios [10]. Energy demand is expected to increase by about a third from 2014 to 2040 [8]. At the same time water demand is predicted to increase by up to 55% by 2050 [11]. This will occur as a result of the increase in global population from about 7.3 billion in 2015 to about 9.7 billion in 2050 [12] and the accompanying increases in food demand, economic growth and industrial activity. While demands are increasing, the amount of global water remains roughly constant at about 1.4 billion km³ [13] with less than 1% being freshwater available for human uses. Accessible freshwater resources are becoming even more vulnerable due to increased pollution, uncontrolled groundwater depletion and climate change impacts on water availability patterns. According to the Intergovernmental Panel on Climate Change [14], the population at risk of increased water stress due to climate change can reach as high as 2 billion in 2040.

The problem is further complicated by the high

interdependence of water and energy. Water is used in all phases of the energy cycle: in extraction and mining, directly in hydro-power generation, for power plant cooling and to irrigate biofuel crops. At the same time, energy is needed in all phases of the water cycle: water extraction and pumping, desalination, purification and distribution to end users. In 2010 the world energy production was responsible for 15% (583 billion cubic meters (bcm)) of total global water withdrawals, of which about 10% (66 bcm) was consumed [15]. By 2035, in the International Energy Agency (IEA) New Policies Scenario, global energy consumption rises by 35% with a corresponding increase in water withdrawals by the energy sector of 20%, while water consumption is expected to increase by 85%. The higher water consumption relative to withdrawals is predicted as a result of shifting to power plants with advanced cooling technologies which withdraw less water but consume more as well as due to the possible expansion of biofuel crops [16]. The degree of interdependence between the two systems can vary regionally based on the distribution of natural resources and existing state of infrastructure. For example, electricity consumption by the water sector varies from 5.8% in Spain (excluding end-water-use energy) [17] to about 9% in the Middle East and North African (MENA) countries [18], 12% in Ontario, Canada and 19% in California [19]. Similarly, the energy sector in the MENA regions consumes less than 0.5% of its freshwater resources, in Spain the energy sector withdraws 25% and consumes about 4%, while in the United States, water use for energy accounts for about 40% of freshwater withdrawals and 4% of consumption [20].

The problem to address then, is tackling the issue of expected energy and water scarcity in the future, by improving existing management methodologies. The overall goal is to manage the supply of water and energy to multiple sectors competing for the two resources while meeting the multiple, sometimes conflicting objectives which may include adaptation strategies, costs, emissions, efficiency, international mitigation commitments and other policies.

The escalating issues emphasize that planners no longer have the luxury to ignore the missed opportunities to be gained from integrated planning and in recent years several international organizations have identified the water-energy nexus as a key global challenge in the upcoming decades (e.g. World Bank: Thirsty energy [21], UN World Water Development Report 2014: Water and Energy [22], Asian Development Bank (ADB): Thinking about water differently [23], US Department of Energy(USDOE): The Water Energy Nexus [24], World Business Council for Sustainable Development (WBCSD): Water, food and energy nexus challenges [25], World Resources Institute (WRI): Water-energy nexus. Business risks and rewards [26], International Renewable Energy Agency (IRENA): Renewable energy in the water, energy and food nexus [27]).

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