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The Nuclear Water Footprint in Spain

Freshwater for Cooling Needs: A Long-Run Approach to the Nuclear Water Footprint in Spain

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ABSTRACT

From the invention of the steam engine to the present, water has represented a significant input to the energy system, although this has been mostly ignored in the literature. In Spain, the most arid country in Europe, studies about water footprint typically just consider domestic, agricultural and industrial water uses, but water requirements for the electricity sector are omitted despite our dependence on thermal power. It has been demonstrated that for each available cooling technology, nuclear needs and consumption of water tend to be larger per MWh generated. We calculate a first approximation to the Spanish nuclear water footprint from 1969 to 2014. Our results show that while water consumed by Spanish nuclear power plants are around 3 m^3 per capita/year, water withdrawals per capita/year are around 70 m^3. Moreover, our analysis allows extracting conclusions focusing on a River Basins approach. What is the water impact of our nuclear power plants? Will water limit our energy future? These are some of the issues at stake.

1. Introduction

From the invention of the steam engine to the present, water has represented a significant input to the energy system, although this has been mostly ignored in the literature. The production of electrical power results in one of the largest uses of water worldwide. When accounting total volumes of water in the energy sector we differentiate within water withdrawals (the total amount of water removed from a source) and water consumption (the amount lost to evaporation that is not returned to the source). For example, it is estimated that in 2005 in the US about 41% of freshwater withdrawals were dedicated to electric production from thermoelectric plants, mainly for cooling (Kenny et al., 2009). Likewise, in the year 2010, France withdrew 22 km^3 of water for cooling purposes and 20 km^3 in the case of Germany (EUROSTAT, 2014). Moreover, about 80% of the world's electricity is generated in thermal power plants (IEA, 2013). In other words, 80% of the world's electricity generation would cease to exist in absence of water; if we add the percentage corresponding to hydropower, the number will be close to 95%. Thus, we must start thinking of water as the most needed natural resource for electricity generation.

Energy and water are valuable resources that support human wellbeing (Brundtland et al., 1987). Consequently, the mutual vulnerability of water and energy is considered one of the most important concerns of the future and, for this reason, it remains a challenge in achieving the Millennium Development Goals (MDGs). In this context, great amounts of water are needed in power generation, mainly for cooling processes, and the water sector needs energy to extract, treat and transport water. Several trends point to rising demands on energy and water because of the growth of population and expansion of economies. Therefore, ensuring the provision of water and energy in the future is essential to guarantee the sustainable development of many countries. In addition, climate change is causing the continued deterioration of global water sources. To this aim, several organizations and institutions have developed proposals to address the challenges of energy resources planning and water. Among these we can find the UN-Water Inter-agency, the World Water Forums, and the Thirsty-Energy Initiative launched by the World Bank. The UN-Water Interagency coordinates the work of the United Nations on freshwater and sanitation,

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including surface water and groundwater resources, the interface between freshwater and seawater and water-related disasters.[1] Similarly, the World Energy Council and the World Water Council through the World Water Forums spotlight the importance of water on the political agenda.[2] Finally, the Thirsty- Energy Initiative from the World Bank introduces a wide variety of regulations and management actions in order to help governments to ensure water and energy for future generations.[3] In other words, '*Thirsty Energy quantifies trade-offs and identifies synergies between water and energy resource management*' (Rodriguez et al., 2013).

Water for thermoelectric power is used in generating electricity with steam-driven turbine generators and to cool the power-producing equipment. The water constraint has already impacted the energy sector in many parts of the world. Some examples are the U.S, France, India, China or Brazil (Rodriguez et al., 2013). Among the available thermoelectric technologies, it has been demonstrated that nuclear power requires the largest amounts of water of the sector. In other words, for each available cooling technology, nuclear withdrawals and consumption of water tend to be larger per MWh generated (IEA, 2012).[4] The use of nuclear energy is one of the heated debates in many societies although nuclear energy meets more than 20% of electricity in OECD countries (Zohuri, 2016). But the discussions concentrate on other aspects of nuclear power (over all, radiation risks and spent fuel management) rather than on the freshwater requirements for nuclear generation.

In an international context, Spain, the most arid country in Europe, appears among the top ten producers of nuclear energy in the world (IAEA, 2015). Therefore, acquiring the knowledge of the Spanish position in this area is essential to provide the necessary judgment tools for the optimal decision-making processes by public authorities, and both public and private business community. As the literature review below reveals, in Spain, unlike other countries, the water problem within energy sector has not yet been considered.

This paper pioneers a first approximation to the water requirements of the Spanish nuclear power plants from 1969 to 2015. In other words, our aim is to calculate the consumptive use of water (i.e. the amount of water evaporated, transpired, or incorporated in energy production) by Spanish nuclear power plants, and the amounts of water withdrawals required for running nuclear power plants. Even if large portions of the water required return to the rivers, yet the opportunity cost exists for such water volumes. Our results show that water withdrawn from rivers by Spanish nuclear power plants is around 70 m^3 per capita in 2014. Likewise, water consumed (i.e. evaporated) by Spanish nuclear power plants is equivalent to around 3 m^3 per capita for the same year. The results also allow the comparison between sectors (for example, water for agricultural or urban uses) allowing us to scale the figures and appreciate the importance of this analysis. This study contributes to a better understanding of the necessary freshwater resources to produce nuclear electricity in Spain and raise awareness about the importance of this issue in a country where the water-energy nexus is not a priority on the political agenda. What is the water impact of our nuclear power plants? Will water limit our energy future? Should water be considered when planning the electricity mix in the future? These are some of the issues at stake.

[1] For more information about UN-Water, see (http://www.unwater.org)

[2] For more information, see (http://www.worldwaterforum5.org)

[3] For more information about Thirsty Energy Initiative, see (http://www.worldbank.org/en/topic/sustainabledevelopment/brief/water-energy-nexus)

[4] Friends of the Earth Association (Australia) in its Anti-Nuclear & Clean Energy Campaign about nuclear power and water consumption states that '*a megawatt-hour (MWh) of electricity from coal uses 20 to 270 l of water at the coal mining stage and an additional 1200 to 2000 l when the energy in the coal is converted to electricity, totaling 1220 to 2270 l of water consumed per MWh. In comparison, nuclear energy uses 170 to 570 l of water per MWh during the mining of uranium and production of the reactor fuel and an additional 2700 l per MWh as the energy from nuclear fission is converted to electricity, for a total of 2870 to 3270 l of water consumed per MWh*'. [www.foe.org.au/anti-nuclearJanuary 2013]

The rest of the paper is structured as follows: Section 2 presents the background and the literature review; Section 3 explains the methodology and data used; Section 4 discusses the results and main conclusions. Finally, Section 5 reviews the potential uncertainties and limitations of the analysis presented.

2. Background & Literature Review

The problem of the interdependence between water and energy is gaining importance because of their demand increases in the future. Accordingly, there are several international studies on the relationship between energy production and water (Malik, 2002; Kahrl and Roland-Holst, 2008; Perrone et al., 2011; Siddiqi and Anadon, 2011; Spang et al., 2014; Jägerskog et al., 2014). The expanding literature on the water-energy nexus developed different approaches to the issue. Rodriguez et al. (2013) analyze the issue by looking at the general water requirements for power generation, and introducing improvement proposals. Delgado et al. (2015) introduce the same problem, but from a more technical perspective. These authors add some explanations related to cooling systems, steam cycle processes, heat balance, and the efficiency in thermal power plants. For its part, the International Energy Agency (2012) provides data about global water withdrawals for power generation and water requirements in the energy sector, and analyses possible future scenarios leaving over the air a question: Is energy becoming a thirstier resource? Likewise, Morrison et al. (2009) highlight the intensifying conflict between energy use and water availability and suggest some guidelines that companies should take to evaluate and address water risks. Siddiqi and Anadon (2011) analyze water intensity throughout the different segments of the energy value chain (i.e. fuel extraction, refining, electricity generation) and calculate the energy intensity of the water value chain. Finally, WWAP (2014) produced a very extensive report about the linkages between freshwater and energy. In the first stage the report introduces the status, trends and challenges related to the water-energy nexus. After that, different central themes and regional areas are analyzed, keeping space at the end for new guidelines and good practices.

More to our point of interest, some articles and technical reports describe the water requirements of power production by cooling technology and several methodologies to calculate water footprint and asses the impacts of water uses. For example, Jeswani and Azapagic (2011) is a good example showing that. In this case, authors analyze some methodological developments which propose methods for inventory modelling and impact assessment for water use in life cycle assessment. Alternatively, Dodder (2014) provides a systems-level perspective regarding different power technologies and Meldrum et al. (2013) and Macknick et al. (2012) introduce a review and harmonization of water withdrawal and water consumption factors found in the literature. Moreover, Delgado Martín (2012) in her doctoral thesis analyses the water use in power plants from a technological perspective through a model based on the heat balance of the power plant. Feeley et al. (2008) also analyses water availability in a power generation context for the development of a program to reduce the water withdrawals and consumptions in the future. In contrast, Spang et al. (2014) explore the geographic distribution of water use by national energy portfolios. They define and calculate an indicator to compare the water consumption of energy production for over 150 countries for year 2008. For their part, Flörke et al. (2011) assess future changes in freshwater needs on electric sector in Europe thought the combination of two approaches: a scenario approach and a modelling approach. In fact, there exists an expanding literature of technical reports on the water required for electricity production: Torcellini et al. (2003), IAEA (2012), EPRI (2000), Averyt et al. (2011), and Kohli and Frenken (2011).

Other strain of the literature concentrates on the potential water quality and ecosystem impacts by the energy sector. For instance, water withdrawn for cooling but not consumed returns to the environment at a higher temperature affecting to surface water and aquatic