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Adaptation to climate-induced regional water constraints in the Spanish energy sector: An integrated assessment

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HIGHLIGHTS

- Spatial and temporal water constraints are added to an energy planning model.
- Integrated water-energy planning can lead to significant savings in future water-stressed scenarios.
- Actual value of water for the energy sector may be much higher than existing prices.

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ABSTRACT

The energy sector depends on water in all phases of its life-cycle, including raw material extraction, power plant cooling, irrigation of biofuel crops and directly in hydropower generation. In the coming decades, several regions of the world are expected to experience a decrease in water resource availability, in part due to climate change. The dependence of the energy sector on water resources calls for an active effort to adapt to the possible scenarios. This paper presents a novel model that addresses the direct impacts of regional and temporal water shortages on energy operation and investment decisions. The paper investigates the costs and benefits of adapting the energy sector to climate-induced water scarcity. The results show that the increase in costs for an energy plan that considers future water stress is relatively small as compared to one which ignores it. A plan which ignores water constraints, however, may lead to significant economic damages when actually exposed to water shortages. The results also highlight the value of the availability of water for the energy sector, which is significantly higher than existing prices. The paper concludes that the potential benefits to be gained by integrating energy and water models can be considerable.

1. Introduction

The International Energy Agency (International Energy Agency (IEA), 2015) estimates that the world energy use will increase by one third by 2040. However, most of the increase will come from Non-OECD (Organisation for Economic Co-operation and Development) countries. In Spain, an energy use peak was reached in 2007, followed by a decline due to the economic crisis, as well as demographic, economic and energy efficiency changes. Forecasts show GDP growth rates of 0.8% in 2015 decreasing to 0.5% by 2020 (Organisation for Economic Co-operation and Development (OECD), 2016) (Trading Economics, 2016). Population is expected to decline by 1 million inhabitants by 2024 and by 5 million by 2064 (Institute Nacional de Estadística (INE), 2014). The energy future is unpredictable with future forecasts for 2020 estimating gross final energy consumption to vary between scenarios from 10% to −5% compared to 2005 values, while electricity generation is expected to increase between 20% and 40% compared to 2005 (Ministerio de Industria et al., 2010) (International Energy Agency (IEA), 2015). The electricity expansion is expected to come mostly from increased natural gas and renewables in the form of wind and solar. With the push for decarbonization, increased energy efficiency, uncertainty about nuclear policies, electric vehicle integration, biofuel alternatives to transport fuels and variable oil prices, the future energy mix is unpredictable with several possibilities for Spain.

In the water sector the main challenges in Spain relate to climate change-related declining water resources in the southeastern river basins (CEDEX, 2012). Already, Spain ranks as one of the most water-stressed nations in the European Union, with several southeastern river basins categorized as severely stressed,

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exploiting more than 40% of the available renewable resources in 2012 (European Environment Agency (EEA), 2012). In all its future scenarios (Pessimistic, optimistic and business as usual) for 2020, 2030 and 2040, the World Resource Institute forecasts water stress in Spain's southeastern basins to become "Extremely high" with water use to available resource ratios higher than 80% (World Resources Institute (WRI), 2016). In addition, Spain's water infrastructure suffers from water losses of up to 20% (Lallana, 2003) (Environmental Resources Management (ERM), 2013).

The existing water withdrawals by the energy sector (not including hydropower) in Spain are estimated at 25% of total withdrawals, while water consumption is estimated at 1.4% of total consumption (Hardy et al., 2012, Evaluation of Spain's Water Energy Nexus). Energy policies and subsequent growth of different energy technologies will have a huge impact on these percentages. For example, bioethanol and biodiesel consume almost 100 times more water than that needed for nuclear, concentrated solar power (CSP) and coal fired power plants. In turn, nuclear, CSP and coal plants consume several times more water than combined cycle natural gas plants, while wind and solar PV hardly consume any water.

Preparation for the possible changes in technologies, as well as the need to replace old equipment, will require massive investments in generation and transport infrastructures in the coming years. But, given the time scales involved, these investments must be planned taking into account the significant way in which climate change may affect them. On the one hand, climate change mitigation policies will require a large part of the investments to be directed towards low-carbon technologies. On the other hand, investment plans need to be adapted to changes in the climate, which will affect both energy demand and supply (IPCC, 2014).

One of the major elements through which the change in climate will affect energy supply and demand is the change in the temporal and regional availability of water as well as changes in water temperature (van Vliet et al., 2013, 2012). Water is used in the energy sector in many ways, but mostly for cooling thermal power plants, for generating hydroelectricity, and for irrigating biofuels. A change in the availability of water would therefore clearly affect these technologies. Indeed, cooling methods are already shifting from traditional once-through cooling cycles to closed loop tower and pond cooling cycles, which are more water consumptive but withdraw less water (Martin, 2012). In the International Energy Agency (IEA), New Policies Scenario, from 2010 to 2035, global water withdrawals by the energy sector increase by about 20% while water consumption increases by up to 85% as a result of higher efficiency plants with advanced cooling methods, as well as due to the expansion of biofuel crops (IEA, 2012). These important implications of changes in water consumption and withdrawals patterns need be taken into consideration in future energy decisions and strategies in Spain.

Increased evapotranspiration and decreased runoff due to climate change will have a significant impact on decreasing hydroelectricity production in several regions of the world including Spain (van Vliet et al., 2013, Global river discharge and water temperature under climate change) (World Bank, 2014). The agriculture sector, which is the largest consumer of water globally, will need to grow considerably, in order to meet the needs of the increasing global population to about 9 billion in 2050. Some studies estimate increases of almost 70% in world agriculture production by 2050 (Hoff, 2011). In Spain, changing trends in agriculture irrigation practices, in response to increased efforts for higher efficiency, can lead to significantly different agriculture water demands. Shifting from rain-fed to irrigation systems can lead to four times more water demand from agriculture as compared to only upgrading existing systems to pressurized drip irrigation systems (Daccache et al., 2014). The importance of correctly accounting for water availability and demands in future energy systems is thus critical, and has already prompted a large research effort into what is generally called the water-energy nexus.

Many recent case studies show that ignoring this interdependency in planning decisions can lead to serious consequences for both sectors. A case study on California (Stokes and Horvath, 2009), a region which has been suffering from a serious drought for the past several years, shows that if California were to meet its future freshwater needs using desalination the process would use 52% of the entire state's energy budget.

We see similar consequences when considering water intensive biofuels as alternatives to traditional fossil fuels in the transport sector. As part of the push for renewable energy expansion, the 2020 European Union renewable energy targets (Renewable Energy Directive 2009/28/EC) initially set a 10% goal for biofuels in the transport sector. A report from 2014 (European Forum for Renewable Energy Sources (EUFORES), 2014) showed that by 2012 Spain was lagging behind in this area (with only 0.4% renewables in the transport sector compared to the 2012 goal of 7.6%). However, while biofuels may address emissions issues, given the high water consumption intensity of biofuels the impacts on water resources can be significant. A study from Spain (Carrillo and Frei, 2009) shows the water impacts of different biofuel percentages in future energy mixes. The biofuels considered include the cultivation and production of biomass to produce bioethanol, biodiesel and biogas. The study shows that increasing the percentage of biofuels in the transport sector from 3% to 5.75%, from 2005 to 2030, would increase the water consumption of the sector more than 4 times (Carrillo and Frei, 2009). They further reported that if all the biofuel demand was locally cultivated and produced it would double the total water consumption of the entire Spanish population. This clearly shows that it makes little sense to promote this type of biofuels.[1]

Therefore, we see that investments in future energy systems need to account for the water-energy nexus, and in particular, for the impact of climate-induced water constraints on these systems. Planning methodologies and models must address this element to create resilient strategies for the energy sector. Unfortunately, as discussed later, current practices and models tend to ignore water constraints in an integrated way. This paper presents the results from a new, integrated water-energy model that includes spatially and temporally disaggregated water demands and constraints, and is therefore capable of addressing some of the shortcomings of existing planning models. The results show the costs and benefits of energy planning with adaptation strategies to account for climate-induced water scarcity. Spain is used as a representative example of a region expected to suffer from significant climate-induced water scarcity in the next few decades.

Section 2 reviews the state of the art and the development of contemporary water-energy models. Section 3 describes the methodology used to create the current model while Section 4 discusses the strategy used in analyzing the benefits of utilizing an adaptation strategy. Section 5 presents the results of a case study applied to the Spanish energy system and Section 6 offers some conclusions and policy recommendations.

[1] In addition to the water requirements, biofuels often displace existing croplands into grasslands and forests, which are carbon sinks absorbing high levels of CO_2. This indirect landuse change (ILUC) is shown to offset emissions savings and resulted in the passing of the EU Directive 2015/1513 (ILUC Directive) limiting the share of biofuels to 7% form the previous 10%.

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