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MEDEAS

MODELING THE RENEWABLE ENERGY TRANSITION IN EUROPE

Project Nr: 691287

Guiding European Policy toward a low-carbon economy. Modelling sustainable Energy system Development under Environmental And Socioeconomic constraints

Annex 11: Task 2.2.e.5 Water Uses due to the transition to a low-carbon economy

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Authors: Laixiang Sun, Klaus Hubacek, Yang Yu, Kuishuang Feng

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MEDEAS
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Scope of document

In this report we examine the existing works on water withdrawal and water use in relation to energy sectors, with an emphasis on drawing the prospects for MEDEAS modeling and for transition to the low-carbon era from the technological and scientific viewpoints. We highlight the relevant problems, constraints and possible solutions for the modeling analysis.

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List of abbreviations and acronyms

NACE – The Statistical classification of economic activities in the European Community

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Introduction

Water is an important input for nearly all forms of energy production, from fossil-fuel extraction, transport and processing, to power production and irrigation of feedstock for biofuels. According to the European Environment Agency (2016), at the EU aggregation and excluding irrigation of feedstock for biofuels, the energy sector accounts for about 20% of total water use and the electricity sector accounts for about 18% of the total water use (Figure 1).

Although at the EU aggregation, water shortage is not a concern, it is well-known that water resources are unevenly distributed across countries and regions of Europe. The same amount of water consumption in a water scarce region may lead to severe environmental impacts compared with the impacts in a water-rich region. Thus, ***it is crucial to take water scarcity into account when assess the impacts of low carbon pathway on water***.

There are some studies that give a broad overview on water use in the energy sector (Pfister et al., 2009; European Environment Agency, 2016, World Energy Outlook, 2016). A general observation in these overview is that water requirements within the energy system are constituted by thermoelectric generation. As a result, the majority of the literature emphasizes quantification of thermoelectric water use. For example, the most recent work of IIASA on "Energy sector water use implications of a 2°C climate policy" (Fricko et al., 2016) focuses on freshwater withdrawal and consumption in the steam-cycle and cooling systems of thermoelectric generation.

In this report, we focus on scarce water consumption for electricity generation across EU countries. We discuss key characteristics of water use by different energy technologies. Our literature review discussion is based on IIASA's work on "Energy sector water use implications of a 2°C climate policy" (Fricko et al., 2016), which has a global focus, and on Pfister et al. (2009, 2011).

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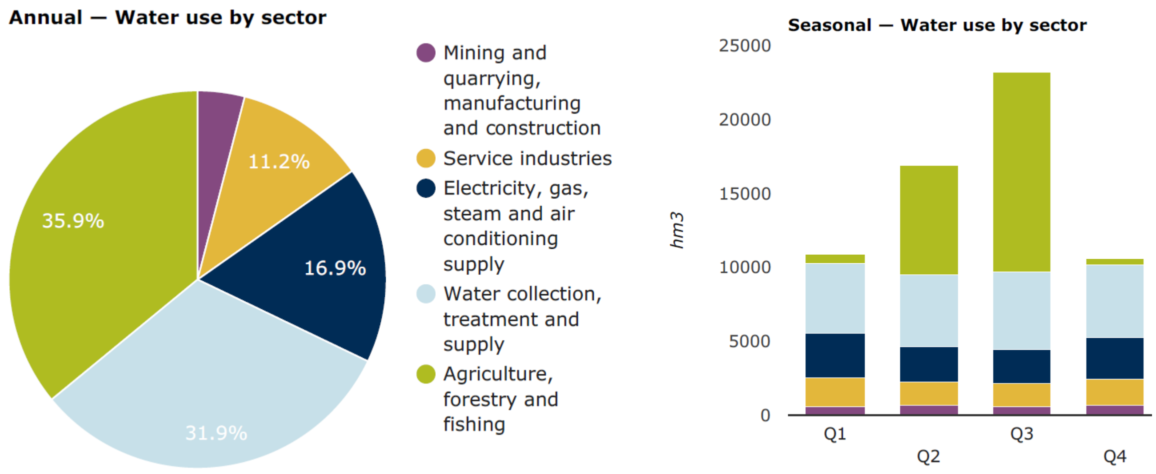

Figure 1 : Freshwater use by sector in Europe. Note: For the pie chart, the data series are calculated as the 2002-2012 multi-annual average for water use by sector at the sub-basin scale. The multi-annual average of quarterly values has been used to develop seasonal water use by sectors. Economic sectors were identified according to the NACE classes.

Source: European Environment Agency (2016), Use of freshwater resources. Available at: http://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-1

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Thermoelectric water use

Steam-cycle power generator utilizes significant amount of water to produce the steam that drives the electric turbines. The thermal process of power generation also produces a significant amount of waste heat. In order to maintain operational efficiency and to prevent long-term damage caused by excessive heat, thermoelectric generation process must incorporate cooling system. Water is typically used as the working fluid in the cooling system to provide the required heat transfer capabilities. Three types of cooling technologies are mostly commonly applied: once-through, closed-loop, and air-cooled systems. Once-through cooling technology involves passing water through the cooling system once, and then returning the water to its source. In contrast, closed-loop systems re-circulate water that is withdrawn. Air-cooled systems rely on air for cooling, and therefore provide an opportunity to reduce the reliance of energy system on water.

There are trade-off issues in terms of water efficiencies and economic costs between the cooling technologies. For example, a once-through system requires significantly more water withdrawn than a closed-loop system for an equivalent amount of power generation. Conversely, the recirculation of water in closed-loop systems results in more evaporative losses, or higher water consumption. Cooling towers are usually needed for the release of the evaporated water, which adds to the cost of closed-loop systems. Differing management practices and environmental regulations for the effluent streams also add impacts on relative performance of the alternative technologies. Once-through systems return water to the aquatic environment at much higher temperatures than closed loop systems, which may require development of ancillary cooling ponds to prevent excessive thermal pollution. Although air-cooling provides an opportunity to break the reliance on water, these systems are the most expansive ones, and operate at lower cooling efficiencies than water-cooled technology. As a result, air-cooled fossil fuel thermoelectric generators typically emit more GHG per unit of fuel than those being water-cooled. Hybrid cooling options do exist, and have the potential to overcome tradeoffs between cooling technology types, but they are the most complicated and associated with the highest capital costs.

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Representation of thermoelectric water use in IIASA's model

Delgado and Herzog (2012) explain how water withdrawals and consumption can be calculated for both once-through and closed-loop cooling systems and for different technology levels, based on the basic principal of how thermal power plants function. Their calculation formula is also adopted in IIASA's research on "Energy sector water use implications of a 2°C climate policy" (Fricko et al., 2016). The simplified version of the formula highlights the three main parameters as a function of the heat rate, which is the amount of energy needed generate one kWh of output:

$$i = \alpha\cdot(\varepsilon-\beta) + \delta, \quad (1)$$

where ε represents the heat-rate (kWh heat/kWh net power output), α represents how efficiently the cooling technology utilizes water (m^3/kWh heat), β represents other heat outputs (heat content of electricity and other heat losses such as with flue gases; kWh heat/kWh net power output), and δ represents water requirements other than for cooling (m^3/kWh net power output). According to this equation the water requirement for a specific power plant is determined by the amount of heat dissipated through the cooling system (ε - β), the type of cooling system employed (α) and other plant specific water requirements (δ), such as flue-gas-desulfurization, gasification processes or boiler feed make-up water. Delgado and Herzog (2012) provide the reference coefficients for various thermoelectric power plants. Most sources do not explicitly detail these "other" water requirements, but provide several approximations of water required for the non-cooling processes in power-plants.

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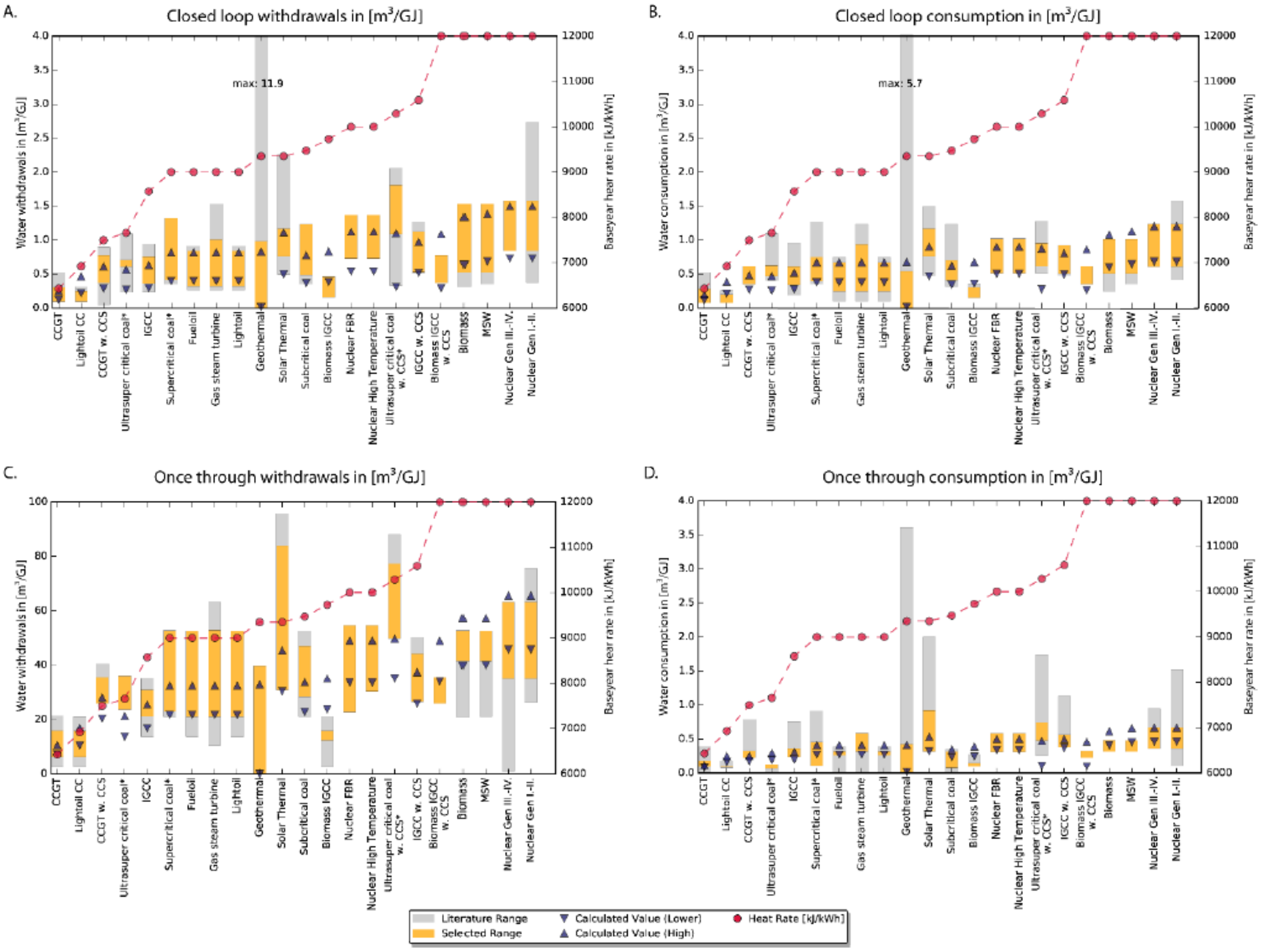

Figure 2 : Range in water intensity coefficients for thermoelectric power plants obtained from the literature review and calculated with Equ. 1 for: (A) withdrawal, closed loop cooling systems; (B) consumption, closed loop cooling systems; (C) withdrawal, once-through cooling systems; and (D) consumption, once through cooling systems (Fricko et al., 2016).

Figure 2 is taken from Fricko et al. (2016, Fig S2.1), which summarizes the water withdrawal- and consumption coefficients for thermoelectric power plants estimated from the literature, as well as the estimates obtained from the approach proposed by Delgado and Herzog (2012). An upper and lower value of water use coefficients for each technology (dark-blue lines; triangle markers depict upper- and square markers depict the lower-coefficient) are included in the MESSAGE modelling analysis of IIASA. The higher water intensity coefficient is applied generally to regions, where either the operation and maintenance of power plants is generally not level to that of Western Europe or the United States, for which the medium coefficient is assumed, or where the mean ambient temperature across the year is relatively high, therefore reducing the effectiveness of the

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cooling system. The lower coefficient is used as an indicator of the potentially achievable water intensity assuming technological improvements of the current cooling technologies. In some regions, even though it may be possible to realize these efficiencies technically, the operational conditions may not permit achieving these low intensities. Data gaps are reflected by the lack of a grey bar, which indicates the literature data range. In such cases, water use coefficients were established based on the technology specific heat-rate and cross comparing water requirements between other technologies with similar characteristics, as well as by looking at available data for other cooling systems.

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Representation of water use in MEDEAS Model

The IIASA's energy-water nexus model has sufficient sectoral details but treat EU as two integrated regions – Western Europe (WEU) and Eastern Europe (EEU). This means that for the EU-aggregation run of the MEDEAS model, we can adopt water withdrawal and consumption parameters from IIASA's energy-water nexus model. However, for national-level run of MEDEAS model, we need to calibrate water withdrawal and consumption parameters at the national level with sufficient sectoral details. For the latter demand, we can adopt water withdrawal and consumption coefficients for electric power generation from the group for Ecological Systems Design at the Institute of Environmental Engineering, ETH Zurich (http://archive.baug.ethz.ch/www.ifu.ethz.ch/ESD/downloads/WATER_DATA.html). As explained in Pfister et al., (2011), ETH's water withdrawal and consumption coefficients for electricity power generation in different countries is based on individual country's energy mix.

Another important perspective is that we should ***take water scarcity into account when assess the impacts of low carbon pathway on water*** as we highlighted in the introduction. Water stress is commonly defined as the ratio of total annual freshwater withdrawals to hydrological availability. Pfister et al. (2009) advanced the water stress concept to calculate a water stress index, ranging from 0 (no stress) to 1 (maximum stress), following a logistic curve to represent commonly reported thresholds for water stress levels. ETH team also provides data on water stress index. The aggregation of this index is freely downloadable from the above web-site. The maps of the index across 50x50km grid-cells are accessible based on signing a collaboration agreement.

Figure 3 shows the significant variation of industrial water scarcity index cross EU countries. The water stress indices of industrial sectors for Cyprus, Belgium, Spain and Greece are larger than 0.7, which indicates severe water scarcity in these four countries. In contrast, Sweden, Lithuania, Estonia, Ireland and Latvia are water abundance countries with their WSI close to zero.

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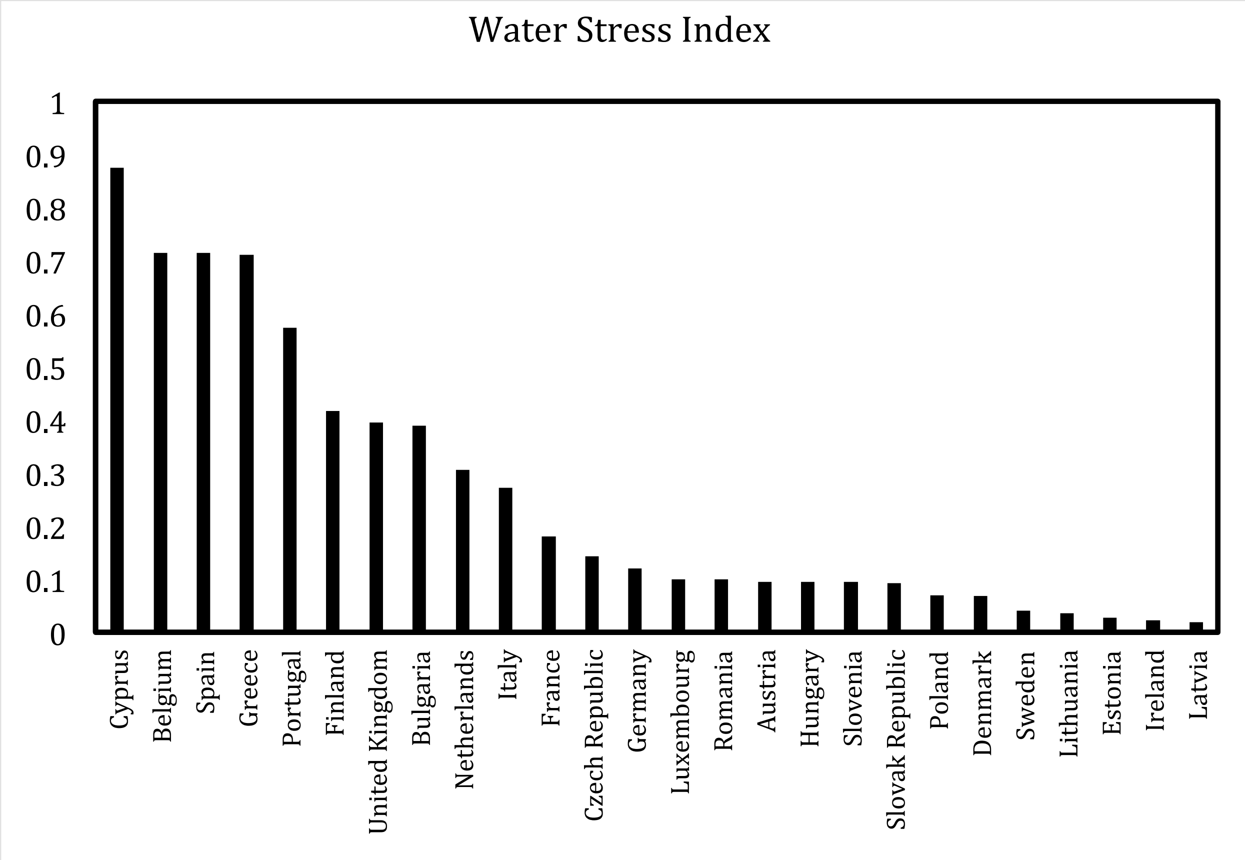

Figure 3 : Water scarcity index of the industrial sector across EU countries

Figure 4 shows water consumption and scarce water per unit electricity generation in the EU countries. From the figure we can see that electricity generation in Latvia, Romania, Austria and Sweden are much water intensive for one unit of electricity output (MWH). For example, one MWH electricity output in Latvia consumes more than twice of water compared with most of other EU countries. However, when we take water scarcity into account, Greece, Portugal, Spain and Bulgaria have much higher scarce water consumption for one unit production of electricity. Our results indicate that water scarce countries, such as Greece and Spain need to find a balance of low carbon development and elimination of water scarcity and may be even more beneficial if they promoting less carbon and water intensive electricity generation technologies such as wind and solar powers.

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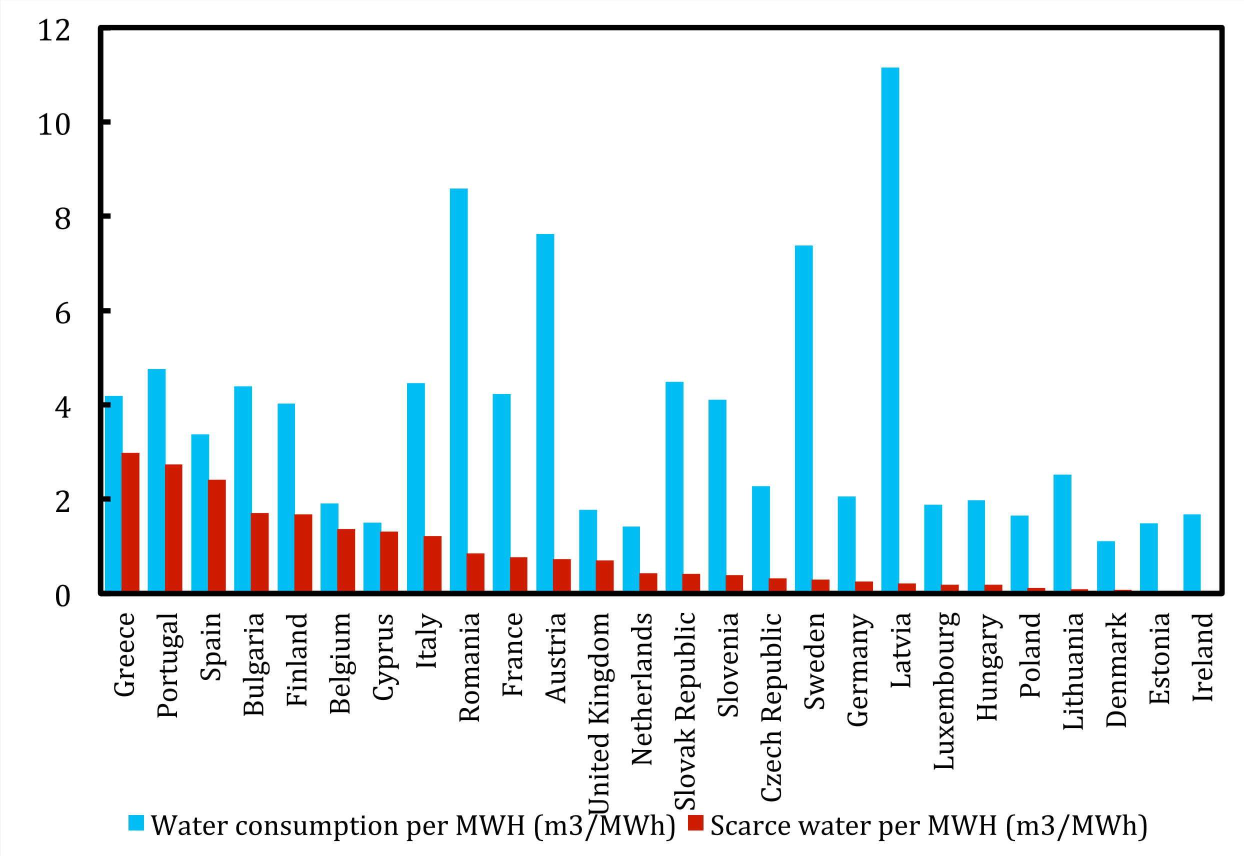

Figure 4 : Water consumption vs. scarce water per unit of electricity production

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Conclusions

Water resources are unevenly distributed across countries and regions of Europe. The same amount of water consumption in a water scarce region may lead to severe environmental impacts compared with the impacts in a water-rich region. Thus, it is crucial to take water scarcity into account when assess the impacts of low carbon pathway on water. The water withdrawal and consumption parameters for MEDEAS run at the EU level can take reference from the IIASA's recent energy-water nexus model (Fricko et al., 2016). The estimation of water consumption coefficients for electric power generation in each EU countries at current technological level is provided by the group for Ecological Systems Design at the Institute of Environmental Engineering, ETH Zurich (http://archive.baug.ethz.ch/www.ifu.ethz.ch/ESD/downloads/WATER_DATA.html). However, the corresponding coefficients for other energy sectors in each EU countries have been missing. For assess the impacts of future low carbon pathway on water, we would have to use water withdrawal and consumption coefficients of individual energy sectors at the EU level, with the assumption that energy supply in general and electricity supply in particular would become more and more integrated.

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