Energy Policy 108 (2017) 844–858

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Water use of the UK thermal electricity generation fleet by 2050: Part 1 identifying the problem

Daniel Murrant[a,*], Andrew Quinn[a], Lee Chapman[b], Chris Heaton[c]

[a] School of Civil Engineering, University of Birmingham, Birmingham, West Midlands B15 2TT, UK
[b] School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, West Midlands B15 2TT, UK
[c] Energy Technologies Institute, Loughborough, East Midlands LE11 3UZ, UK

ARTICLE INFO

Keywords:
Water-energy Nexus
UK energy policy
Water resources
Climate change
Power station cooling

ABSTRACT

The effects of increasing water and energy demand pose a growing threat to national infrastructure strategies. Within the UK there is concern that a future lack of water will compromise the UK's current energy policy to meet an increasing demand for electricity by more thermal generation. This paper investigates this by modelling the water demand of the UK's thermal generation in 2030 and 2050 for several future electricity generation pathways. Unlike previous studies this paper has obtained water abstraction and consumption figures specific to the UK.

While the water demands were heavily pathway dependent this study finds for the thermal generation pathways there is a serious mismatch between the assumed freshwater available at 2030 and 2050, its expected actual availability, and an understanding of the implications this has for future generation costs. It is shown that a solution is to make greater use of the UK's seawater resource. This study finds the emphasis UK energy policy gives to the competing poles of low cost electricity generation and environmental protection will have significant impacts on the cost and make-up of the UK's future electricity generation portfolio. A companion paper will consider the generation cost issues if seawater is not available.

1. Introduction

The interdependencies between the availability of water and the generation of electricity are increasingly posing a threat to many national infrastructure systems (Gu et al., 2014; Hussey and Pittock, 2012; Pacsi et al., 2013; Tran et al., 2014). This is the result of an ever-increasing demand for water and electricity generation associated with a decreasing availability of freshwater for power station cooling water. This reduction in freshwater availability is the result of climate change, increasing demographic issues, and increasingly stringent environmental regulation.

Byers et al. (2014) estimates that up to 90% of water abstracted by power stations is for cooling therefore the cooling method used by power stations dictates their water demand. Once-through cooling uses water to cool a power station's exhaust heat directly and is recognised as the Best Available Technique (BAT) due to its relatively high efficiency, and therefore low cost and CO_2 burn (European Commission, 2001). Of the cooling methods it by far withdraws the greatest volumes of water. There are alternative cooling methods which withdraw less but these are more inefficient and consume more (Byers et al., 2014, 2015; Murrant et al., 2015). Evaporative cooling uses cooling towers and recycles its cooling water, air cooling uses no/negligible water, hybrid cooling systems are a combination of evaporative and air cooling. Although these cooling methods are less water intensive they do carry significant cost penalties (Turnpenny, 2010; Macknick et al., 2011).

For the UK a number of studies have looked at this water-energy nexus issue and the unanimous view was from 2010, through to the 2050s a scarcity of freshwater will increasingly compromise UK thermal power stations' ability to generate electricity (Byers et al., 2014, 2015; Murrant et al., 2015; Schoonbaert, 2012; The Royal Academy of Engineering et al., 2011). From 2010–2050 UK electricity demand is predicted to grow from 384 TW h to a potential 610 TW h (HM Government, 2011; Macleay et al., 2011), with Government policy seeing the means being predominantly an increase in thermal generation (Committee on Climate Change, 2015; DECC, 2015; Government, 2011).

Byers et al. (2014) produced a model framework to quantify the operational water demands of different electricity generation pathways in terms of their water abstraction and consumption demand, per

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[*] Corresponding author.
E-mail address: d.murrant@bham.ac.uk (D. Murrant).

http://dx.doi.org/10.1016/j.enpol.2017.05.011
Received 11 May 2016; Received in revised form 28 March 2017; Accepted 6 May 2017

generation technology, per cooling method, per timeframe. The framework could also distinguish between different cooling water resources; the options being freshwater, estuarine and sea water. To obtain information on the water demands of different generation pathways the Byers' framework was used to model the water demands of six possible future UK electricity generation pathway options, see 2.2 Carbon Plan Pathways.

For Byers et al. (2014) the water abstraction and consumption figures used were based on a study carried out by the USA's National Renewable Energy Laboratory (NREL) (Macknick et al., 2011). The authors of this paper obtained access to UK specific water abstraction and consumption figures compiled by the Joint Environmental Program (JEP), and made available by the Environment Agency (EA). For this paper this data is referred to as the UK abstraction and consumption figures.

The aim of this paper is to consider how the future water demands of UK thermal electricity generation in a freshwater scarce environment could impact UK energy policy. This was achieved by using the Byers et al. (2014) framework, and the UK abstraction and consumption figures to attribute, relative to 2010, national abstraction and consumption water demands to the Energy Technology Institute's (ETI) Energy Systems Modelling Environment (ESME) pathways (see 2.1 Energy Systems Modelling Environment (ESME) model) for 2030 and 2050. Given the importance of the Carbon Plan in setting out how future UK energy policy will aim to achieve decarbonisation (HM Government, 2011), the opportunity will also be taken to update the six 2030 and 2050 pathways analysed by Byers et al. (2014).

2. Background to electricity generation pathways modelled

2.1. Energy Systems Modelling Environment (ESME) model

The ETI is a collaboration between industry and the public sector, formed in 2007, to promote the UK's transition to a low carbon economy (Heaton, 2014). The ETI developed the internationally peer-reviewed ESME model to identify technologies likely to be important for creating an affordable, secure, and sustainable energy system. In addition it was also required to meet the UK's 2050 Greenhouse Gas (GHG) emissions reduction target of 80% from their 1990 levels (Heaton, 2014; Energy Technologies Institute, 2016). Besides being used by the ETI's members and academic institutions ESME was used by the Department of Environment and Climate Change (DECC) when developing the UK's Government's Carbon Plan, and by the Committee on Climate Change (CCC) for their review of carbon budgets (Day, 2012; Heaton, 2014).

ESME is a design tool rather than a forecasting tool and adopts a least-cost optimisation Monte Carlo approach to modelling the UK energy system whilst still adhering to a number of specified targets and constraints. These include emission targets, resource availability, technology build rate, and meeting the projected energy demand. It should be noted that ESME is only constrained by CO_2 emissions rather than all GHG emissions, although the expected pathway of all GHG emissions are taken into account when determining the levels of CO_2 allowed (Heaton, 2014).

When modelling the future UK energy system ESME adopts a whole system scope which includes all the major flows of energy: electricity generation, fuel production, energy use for heating, industrial energy use, and transportation of people and freight. A range of technology options are available encompassing all the energy flows above, including power stations, vehicle and heater type, each with a number of input parameters such as available resources, fuel prices and technology costs (Energy Technologies Institute, 2016).

ESME then uses the least cost optimisation method to analyse the various permutations of technology choices. It selects those which produce the least cost energy system out to 2050 whilst still meeting and adhering to the specified targets and constraints. ESME can model its energy system in either five, or 10 year, time steps from 2015 to show the progression to 2050.

Unlike similar UK energy system models such as MARKAL, rather than providing only national outcomes, ESME can model demands and resources at the UK regional level, and show the regional location of its modelled electricity generation infrastructure (HM Government, 2011). As UK energy demand, water demand, and water availability vary regionally, this regional functionality is an advantage that the use of the ESME model brings to this study. Although for the purpose of this paper, and to provide a starting point for this research, only the 2030 and 2050 national outcomes relative to 2010 will be considered here. The key results and outcomes developed using the modelling analysis described in this paper are then built upon in the companion paper to enable analysis on a regional scale to be undertaken (Murrant et al., 2016).

While at the national and regional level ESME is able to provide least-cost and CO_2 emissions optimised generation pathways it is not able to consider the associated water demand of the modelled pathways. With thermal generation being the major 'intended' electricity generator for many ESME pathways, and with future water availability increasingly an issue, this limits ESME's usefulness as a strategic modelling tool. This is a matter which was resolved at the regional scale by this study and is described in more detail in the companion paper.

2.1.1. Monte Carlo approach

Any model has inherent uncertainties particularly one as complex and broad as ESME. Whilst it is impossible to entirely remove these uncertainties ESME uses the Monte Carlo technique to manage and quantify them. Rather than producing a single perturbation ESME produces hundreds, or even thousands, where the input parameters (e.g. energy resources, fuel prices, technology costs) are varied for each according to the probabilistic distribution of the parameter. This was developed by the ETI in consultation with industry experts. As well as showing the range of individual results a final result is produced by taking the mean average of this range.

This approach allows a range of possible future energy systems to be considered. Besides identifying technologies which appear highly likely to contribute to the future energy system, it also identifies those which may depending on how the input parameters change in the future. This approach was felt to be a further benefit of using the ESME model as it helps to identify the range of uncertainty that policymakers have to consider when taking decisions.

2.1.2. ESME pathways

The results produced by ESME, as with any model depend upon the inputs. When ESME is perturbed with standard probabilistic distribution for each input parameter using the Monte Carlo approach the result is referred to as the Monte Carlo (ESME.MC) pathway. It represents ESME's best design make-up of a 2050 UK electricity generation pathway. When modelling the 2050 pathway it focuses on achieving the UK's CO_2 emission reduction, and electricity generation targets at least-cost. As a result the generating technologies selected are found to favour additional nuclear generation, then CCGT +CCS plant supported by renewables, Fig. 1. The ESME.MC pathway finds a large adoption of nuclear generation results in the cheapest overall energy system because it reduces the need for intermittent renewable energy generation which requires expensive storage and balancing infrastructure. This may appear counter intuitive given that a number of proposed nuclear power stations in Europe including Hinkley Point C are over-budget, however this new generation of nuclear power stations are effectively First Of A Kind and therefore costs can be expected to reduce in the future (Csereklyei, 2016). Furthermore by using its' Monte Carlo approach the ESME.MC pathway does consider a range of capital costs for nuclear power stations, some of which foresee budget overspends of almost 50%.