The water-energy nexus: a growing environmental threat

Florence Bullough

Water stress and scarcity is one of the most urgent cross-cutting challenges facing the world today and is intrinsically linked with the need for energy. Extraction and processing of fuel for electricity supply and transport requires water. Water is used to process fuels, for cooling in power plants and for irrigation in the case of biofuels. Energy is required for pumping, transportation and the purification of water, for desalination, and for wastewater. In the context of rapid global environmental change and a growing population seeking to improve its living conditions, this is a fundamental global challenge.

Les contraintes concernant l'eau et sa raréfaction constituent l'un des défis les plus visibles et les plus urgents auquel le monde doit faire face aujourd'hui, et sont intrinsèquement liées au besoin d'énergie. L'extraction et le traitement du fuel, pour la fourniture d'énergie et les transports, nécessitent de l'eau. L'eau est utilisée dans le traitement des carburants, pour le refroidissement des centrales nucléaires et pour l'irrigation dans le cas de carburants d'origine biologique. De l'énergie est nécessaire pour pomper, transporter et purifier l'eau, pour sa désalinisation et pour les eaux usées. Dans le contexte d'un changement environnemental rapide et global et d'une population croissante cherchant à améliorer ses conditions de vie, il s'agit d'un défi global et fondamental.

La escasez y la tensión hídrica es uno de los retos de la coordinación transversal a los que se enfrenta hoy el mundo y está unida intrínsecamente a la necesidad de energía. La extracción y el tratamiento de combustible para el suministro de electricidad requieren agua. El agua se utiliza para el tratamiento de los combustibles, para el enfriamiento de las plantas de generación y para el riego en el caso de los biocombustibles. Hace falta energía para el bombeo, el transporte y la purificación del agua, para la desalinización y para las aguas residuales. En el contexto de un cambio global rápido y de una población en aumento que busca mejorar sus condiciones de vida, este es un reto global fundamental.

The scarcity of freshwater and drinking water is among the most important cross-cutting challenges in the world today. The issue of water security is intrinsically linked to energy security. Energy production consumes large amounts of water, mainly due to cooling in power plants, and water production requires energy for treatment, pumping and transport. Both are of significant concern in terms of future provision and sustainability. The interconnectedness, as this paper will show, is such that water and energy cannot be addressed as separate entities. This interdependence is termed the 'water-energy nexus', an approach which allows a more holistic, non-reductive assessment of energy and water security issues. Water scarcity is intensifying due to excessive withdrawal, whilst concern for energy provision is sparked by diminishing fossil fuel reserves and the built-in problem of CO_2 emissions and climate change.

Globally, over the last 50 years, the amount of water withdrawals has tripled while the amount of reliable supply has remained constant (Lee *et al.*, 2012) (See ***Fig. 1*** for the distribution of baseline water stress.) This has resulted in depletion of long term water reservoirs and aquifers, most acutely in emerging economies with high population growth such as China, India and areas in the Middle East.

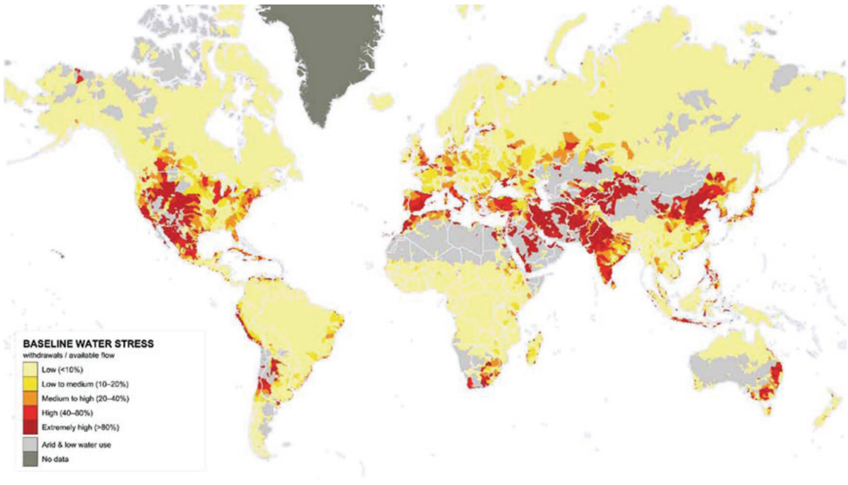

Figure 1: World map of baseline water stress – a measurement of total annual water withdrawals expressed as a percent of the total annual available flow (from Gassert et al.*, 2013).*

The dynamics of the water-energy connection are often misstated, because of confusion over the definition of consumption and withdrawal. ***Consumption*** refers to water that either disappears or is diverted from its source for irrigation or drinking water; this source may or may not be replenished but if so it could potentially take decades, centuries or longer. ***Withdrawal*** is when water is uptaken for a given use, but is then returned to its source, potentially at a lower quality (Glassman *et al.*, 2011).

Water stress and environmental change will increase the strain on energy production in drier areas, while energy shortages will place limitations on water purification and distribution. For this reason, policy frameworks and regulations, devised for the future of water and energy provision,

* Policy Assistant, The Geological Society, Burlington House, London, florence.bullough@geolsoc.org.uk

Energy type	*Water consumed (m^3/MWh)*
Wind	*0.001*
Gas	*1*
Coal	*2*
Nuclear	*2.5*
Oil/Petrol	*4*
Hydropower	*68*
Biofuel, 1st gen. (corn, US)	*184*
Biofuel, 1st gen. (sugar, Brazil)	*293*

Table 1: Comparative water consumption values by energy type (WssTP, 2011).

will require consideration of the interdependence of water and energy.

Energy is limited by water

The energy sector relies heavily on the use and availability of water for many of its core processes. Resource exploitation, the transport of fuels, energy transformation and power plants account for around 35% of water use globally (Lee *et al.*, 2012). Thermoelectric power plants use significant amounts of water and account for the majority of water use by the energy sector. In the USA in 2007, thermoelectric power generation – primarily comprising coal, natural gas and nuclear energy –generated 91% of the total electricity and the associated cooling systems account for 40% of USA freshwater withdrawals (King *et al.*, 2008). This water demand has been exacerbated by the shift from open loop cooling systems to closed loop cooling. Open loop cooling systems have high withdrawals and low consumption, which is preferable but results in the discharge of water at a higher temperature, causing thermal pollution of waterways. For this reason closed loop cooling was adopted, which has low withdrawals but high consumption due to evaporation during re-circulation of the water (King *et al.*, 2008).

Of the different types of power plants, gas-fired plants consume the least water per unit of energy produced, whereas coal-powered plants consume roughly twice as much water, and nuclear plants two to three times as much (WssTP, 2011). By contrast, wind and solar photovoltaic energy consume minimal water and are the most water-efficient forms of electricity production. Comparative water consumption by energy source can be seen in ***Table 1***.

Claims that certain fuels and technologies reduce CO_2 emissions can be misleading, as the consideration of water consumption is often omitted. For example, unconventional fracked gas is often presented as a preferable source of energy over coal due to its reduced associated CO_2 emissions, but the extraction of fracked gas consumes seven times more water than natural gas (Glassman *et al.*, 2011). Additionally, carbon capture and storage (CCS) technology has the capacity to remove CO_2 from the system but is also estimated to need 30-100% more water when added to a coal-fired power plant (Glassman *et al.*, 2011). Looking at carbon intensity alone may set a trajectory to a scenario where electricity production is constrained by water scarcity, while global demand for electricity increases.

The current trend in diversification of energy sources into non-conventional, often lower quality fuels will require increasingly water intensive practices. Extraction of oil from oil sands requires up to 20 times more water than conventional drilling, while biofuels can consume thousands of times more water than conventional fossil fuels due to the need for irrigation (Glassman *et al.*, 2011).

Water limited by Energy

The counterpart to the need for water for energy production is the need for energy in order to produce and deliver water for drinking and other domestic, agricultural and industrial use. Domestic water heating accounts for 3.6% of total USA energy consumption (King *et al.*, 2008). Supply and conveyance of water is also energy-intensive and is estimated to use over 3% of USA total electricity. Energy is required at every step of the supply chain, from pumping ground water (530 kWh M^{-1} for 120 m depth), to surface water treatment (the average plant uses 370 kWh M^{-1}) and transport and home heating (King *et al.*, 2008). Water treatment will require even more energy with the addition of treatment technologies and purification measures. This was evidenced in a recent draft EC directive reviewing the priority substance list under the Water Framework Directive (WFD). Water companies in the UK report increases of over 60% in electricity usage since 1990 due to advanced water treatment and increased connection rates, and conservative estimates predict increases of a further 60-100% over 15 years in order to meet the myriad relevant EU directives (WssTP, 2011). While this increased energy use may contribute to a reduction in water pollution levels, it will lead to higher CO_2 buildup in the atmosphere, thus simply displacing the pollution problem.

Desalination

One of the most problematic developments in the competition for water and energy is the growth of desalination. It is used in areas suffering from water scarcity, but with viable energy sources to power the energy-intensive purification process. In areas such as the Middle East, the Mediterranean and western states of the USA, governments have increased their investment in desalination technology in order to secure a more stable water supply. However, the high-energy requirements, steep operational costs, wastewater disposal issues and large CO_2 emissions often make this an unsustainable solution (Lee *et al.*, 2012) (See ***Fig. 2*** for details on desalination technology and its use in Europe).

Desalination is often made economical through access to cheap, local energy sources and an abundant water source. This usually precludes the adoption of desalination in many land-locked countries, as operational costs increase with distance from the water source (Lee *et al.*, 2012). However, increased water stress is leading to calls for more ambitious projects such as the planned Red Sea–Dead Sea project to build a desalination plant and a 180 km pipeline through Israel, Palestine and Jordan.

The high energy demands of desalination exacerbate water–energy dependence and lead to increased CO_2 emissions. Desalination can use 10-12 times as much energy as standard drinking water treatment, and is expensive and unsustainable (King *et al.*, 2008). These undesirable effects have led to widespread opposition to desalination in areas such as Carlsbad, California (USA) and Chennai (India). Utilising renewable energy resources, coupled with the use of saline or wastewater for cooling at the power plants, could make the process more sustainable.

The Impact of Water Scarcity

Freshwater scarcity is a growing issue and by 2030, demand is set to outstrip supply by 40% (Lee *et al.*, 2013). This is due in part to economic and population growth, but also the rise of aspirational lifestyles, which creates demand for more water-intensive products. This increase in demand will put additional pressure on water-stressed regions, as well as intensifying current transboundary water conflicts. The issue of water shortages often intersects geographically with fragile or weak governments and institutions that may lack the capacity to put in place measures to address water security (Lee *et al.*, 2012). In 2004, 29% of India's groundwater reserves resided in blocks that were rated semi-critical to overexploited (Lee ***et al.***, 2012). About 60% of India's existing and planned power plants are located in water-stressed areas and there are plans to build a further 59 GW of capacity, around 80% of which will be in areas of water stress and scarcity (see ***Fig. 3***). The geography of water scarcity often coincides with emerging economies, the growth of which may be impeded by water scarcity, and this tension could potentially lead to instability.

Desalination Technology and Usage in the EU

Water with a Total Dissolved Solids value exceeding 1,000 mg/L is considered to be saline. Desalination is commonly carried out by one of two methods.

1. Phase change thermal processes
   - Water is heated until evaporation occurs, and the salt is left behind while the vapour condenses to fresh water.
2. Membrane processes.
   - Water is passed through a relatively permeable membrane which induces two zones, one of freshwater and one of saline water. The main separation principle lies in the size of the ions and molecules in the water i.e. salts are bigger than water molecules.

Spain has been using desalination technology since 1964 and Europe has a growing share in global desalination capacity. Desalination in Europe now accounts for 10% of global capacity with countries such as Greece, Italy, and Spain accounting for the majority. Desalination is becoming increasingly used during freshwater scarcity in dry periods and Spain's production has doubled in the last decade.

Bajo Almanzora Desalination Plant in Almeria, Spain-Treats 60,000m3 a day and can serve 15% of the population of Almeria province.

Figure 2: Desalination technology and usage in the EU.

Pressure on water provision, impact on soil quality and aquifer depletion are likely to have damaging effects on food crops and irrigation. Food production will have to compete with other industries for water, which may create economic conflict. There is also concern that some countries will resort to large-scale river redirection projects similar to those seen in China. These affect ecosystems, and also result in significant re-settlement, which in itself has impacts on water supply. The effects can also be felt in other countries downstream, increasing cross-boundary tensions.

Climate change impacts

Environmental change presents a challenge to business-as-usual assumptions about future energy and water provision. Predicted major heat waves and droughts will add pressure to both water and energy security. Climate change is set to affect areas around the world in unprecedented ways; Africa, Asia, Oceania and Latin America are all expected to experience significant water shortages by 2030. In southern Europe, temperatures are likely to rise, and drought will become more common in a region already vulnerable to water stress (Gassert *et al.*, 2013). This is true particularly in Spain, a country that derived 14.3% of its electricity production from hydropower in 2010,

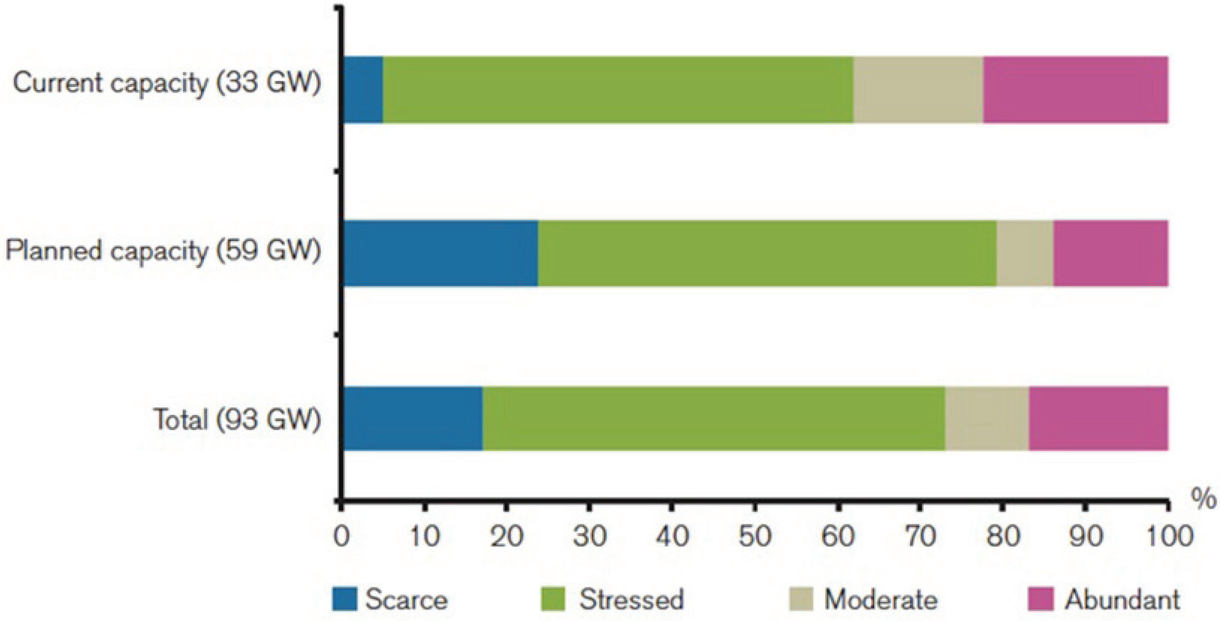

Figure 3: Location of power plants in India with regards to level of water stress (Lee et al.*, 2012).*

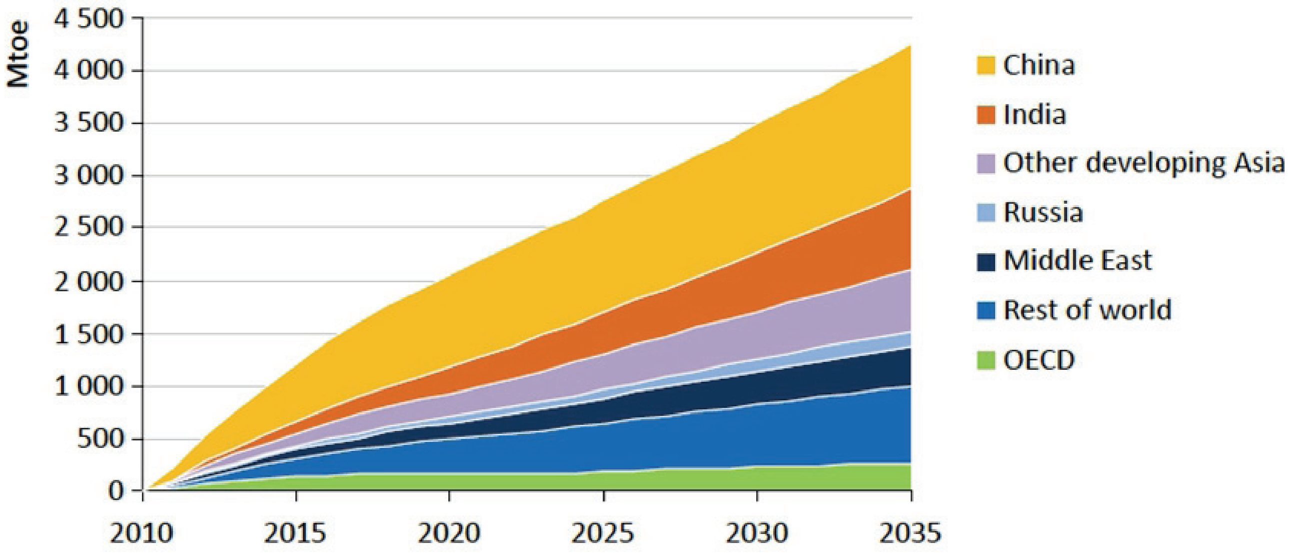

Figure 4: Growth in primary energy demand (in Mtoe) (IEA World Energy Outlook, 2011).

where hydroelectric plants have been under considerable stress in the last 20 years due to long running issues with drought (Perez y Perez *et al.*, 2009; Trading Economics, 2013). As well as hydropower, this is likely to affect tourism and crop productivity, which are both crucial to the economy of the Mediterranean region.

Power cuts caused by extreme weather events, which are expected to become more frequent, will affect areas that rely heavily on energy-intensive ground water extraction for drinking water. In India, for instance, more than 60% of water for irrigation and over 85% of its drinking water comes from pumped groundwater (Lee *et al.*, 2012). Environmental change resulting from our past and current activities will only be exacerbated by increasing energy usage, which, as seen in ***Fig. 4***, is set to increase globally by 67% from 2009 to 2030 if the status quo is maintained (IEA World Energy Outlook, 2011).

Climate change will function as a threat multiplier to the issues outlined above and the wider supply chain as extreme events compromise production and resource infrastructure. Water and energy are set to become increasingly interdependent, and by 2050 water consumption to generate electricity is forecast to more than double (Lee *et al.*, 2012).

What can be done?

Climate change is now considered an issue of national security in many countries, threatening both people and the environment within and across state boundaries. For this reason, climate change mitigation and adaptation must be managed at a new strategic level, beyond that of national law making. A more holistic approach to management of environmental change, water and energy security will also be required. The conflict between more water-intensive energy production and the water needs of a growing population, seeking a better quality of life, will exacerbate an already stressed water-energy nexus. Addressing this challenge will require strategic planning of water and energy security over much longer timescales than previously.

Planning

Incorporation of the water-energy nexus approach into planning and regulation will allow the linked issues identified above to be addressed more effectively. A major challenge will be to adapt the current siting and energy and water delivery systems of cities based on the climate of the last century or so. This will require a paradigm shift to adapt to a rapidly changing climate. Water availability has become a critical determinant for planning and investment in major infrastructure projects such as such as power plants and large-scale residential developments. These must be sited with consideration for water withdrawal, consumption and local power accessibility. Planning should take into account the full effects of the water-energy nexus and future unpredictability in climate, particularly as the lifetime of such developments is several decades or more.

Countries should move away from a single source of energy and water, building adaptability into their energy and water profile to reduce risk. Smaller scale, distributed energy systems may also be more resilient than centralised systems, although these are often difficult to fund. Operating costs and energy and water consumption, not just capital costs, need to be built into the planning phase. Water planning should be based on the catchment-based approach to water use and conservation espoused by the WFD, and discussion between stakeholders should be encouraged.

Regulatory Changes

Another important tool to address these issues is regulation. Current regulatory frameworks such as the European Climate and Energy Package and the WFD need to be developed in light of the water-energy nexus model. The EU is committed to a 20-30% reduction in CO_2 emissions by 2020 compared to levels in 1990, with reductions of up to 50% by 2030 and 80% by 2050 under negotiation. In contrast, the WFD requires additional treatment measures and this will need additional energy, exacerbating tensions between water and energy demand (WssTP, 2011).

There are many policy instruments that can be used to regulate the role of water and energy management, such as water pricing and charges on carbon emissions to provide incentives for sustainable behaviour. The development of CCS technology could reduce the carbon footprint of power plants, but water consumption implications should be taken into consideration. Adoption of disincentives for certain types of land-use change and stricter building and engineering regulations could also be introduced to increase resilience against extreme weather.

The growing geopolitical issues of water location and scarcity will need to be managed through adaptable water sharing agreements, since many of the world's largest and most important river basins – such as the Mekong River, which passes through south-east Asia – cut across many borders. Co-management strategies such as shared water level and quality information will become important so that the water systems can be managed effectively. Governments must also improve their resilience to extreme weather conditions individually and collectively.

A greater focus on recycling energy- and water-intensive commodities would also alleviate water stresses when taken together with other measures. Education about recycling and water and energy conservation programmes could produce benefits, but also require investment and careful management. Conservation or pollution prevention is often more economical than a high-tech approach: generating energy with clean water is very expensive, for instance, whereas the re-use of sea water, wastewater and low quality water for power plant cooling can reduce the overall water footprint of a power plant.

This broad set of issues can only be effectively ameliorated through a holistic approach. A broad analytic framework is needed to evaluate the water-energy relationship, and this must be balanced with local policy contexts and different regulatory measures to ensure that water and energy are sustainably managed in the 21st century.

References

Gassert, F., Landis, M., Luck, M., Reig, P., Shiao, T. 2013. Aqueduct Global Maps 2.0. Aqueduct, World Resources Institute. (accessed March 2013: *http://aqueduct.wri.org/publications*)

Glassman, D., Wucker, M., Isaacman, T., Champilou, C. 2011. The Water-Energy Nexus: Adding Water to the Energy Agenda. A World Policy Paper. (accessed March 2013: *http://www.worldpolicy.org/policy-paper/2011/03/18/water-energy-nexus*)

IEA World Energy Outlook 2011. (accessed March 2013: *http://www.iea.org/newsroomandevents/speeches/AmbJonesDeloitteConference21MayNN.pdf*)

King, C, W., Holman, A, S., Webber, M, E. 2008. Thirst for energy. *Nature Geoscience*, 1. 283-286. DOI 10.1038/ngeo195

Lee, B., Preston, F., Kooroshy, J., Bailey, R., Lahn, G. 2012. Resources Futures. Chatham House. (accessed March 2013: *http://www.chathamhouse.org/publications/papers/view/187947*)

Perez y Perez, L., Barreiro-Hurle, J. 2009. Assessing the socio-economic impacts of drought in the Ebro River Basin. *Spanish Journal of Agricultural Research*, 7(2). 269-280.

Shatat, M., Riffat, S, B,. 2012. Water desalination technologies utilizing conventional and renewable energy sources. *International Journal of Low-Carbon Technologies*, 0. 1-19 (advance publication). DOI 10.1093/ijlct/cts025

Spence, T. 2012. Desalination: Solving water problems or creating a new one? EurActiv.com (accessed here in March 2013: *http://www.euractiv.com/specialreport-delivering-water-2/desalination-solving-water-probl-news-512771*)

Trading Economics. Electricity Production from Hydroelectric Sources (% of total) in Spain. (accessed March 2013: *http://www.tradingeconomics.com/spain/electricity-production-from-hydroelectric-sources-percent-of-total-wb-data.html*)

Water-Technology.net – Bajo Almanzora Desalination plant, Almeria, Spain. (accessed March 2013: *http://www.water-technology.net/projects/bajo-almanzora-desalination-plant/bajo-almanzora-desalination-plant3.html*)

WssTP. The European Water Platform. 2011. Water and Energy: Strategic vision and research needs. (accessed March 2013: *http://www.wsstp.eu/content/default.asp?PageId=750&LanguageId=0*)