WATER-ENERGY NEXUS, PROBLEMS AND PROSPECTS FOR THE UK

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ABSTRACT

Globally, water and energy have been treated autonomously by numerous authors either due to the complex challenges associated with assessing both in concert or given their discrete economic roles. However, contemporary issues of phenomenal climate variability, sustainability, industrialization, population growth and security of supply, present a dire need for an integrated approach to policy formulation and design of water-energy systems in the UK.

Water is a key resource in most sources of energy generation including hydro, thermal and nuclear; in turn, great and growing measure of energy is required to operate and maintain water treatment and distribution facilities. This inextricable but intricate link between water and energy clearly presents both problems and prospects for assessment.

From the study, both sectors heavily rely on each other, as the output of one is the input of the other. Albeit, greater concern is raised in the trend of water sector energy use which is consistently increasing subsequent to the implementation of strict regulatory water regimes that have necessitated the use of more advanced but energy-intensive water and wastewater treatment facilities.

It is believed that this assessment of water and energy resources in tandem will help improve on the design and operation of water-energy systems, enhance the sustainability credential of the undertakings and create more secure integrated services in UK.

Keywords: Water, Energy, Nexus, Problems, Prospects.

INTRODUCTION

Water, energy, waste, transportation, Information and Communication Technology (ICT), etc., all constitute the national infrastructure in UK (Watson and Rai, 2013). These infrastructure sectors contribute in distinct ways to the value chain of each other, giving rise to a complementary relationship which entails a form of support to ailing sectors. It also means that failure of a sector which is heavily relied upon by other sectors will induce a cascade of failures or poor productivity in the dependent sector(s). For instance, electricity failure will critically impact on water processes, while ICT failure will have severe effects on water and power sectors as these greatly rely on ICT (Buldyrev *et al*., 2010). Accordingly, Watson and Rai (2013) have reasoned that a plan to improve drinking water quality or upgrade a wastewater infrastructure may in turn intensify energy input or GHG emissions. Thus, the need to explore the water-energy tie is intensified by the heavy reliance of other sectors on both water and energy.

Water, next to air as the most fundamental requirement of life, is both a human right and an economic good (UNESCO, 2003), while energy is critical to the provision of water. Whereas, water is important in energy production and energy plays a great role in water management, the interdependence of these two resources is known as "water-energy nexus" (Siddiqi and Anadon, 2011).

Several authors have claimed that relative to the significant research efforts in water and energy in isolation, the water-energy nexus remains under-explored globally (Gleick, 1993; Webber, 2008 and Siddiqi & Anadon, 2011). Only a few peer-reviewed literature highlight energy intensities of water abstraction, purification and distribution in UK, as most researches on the water-energy relationship focus on water use in electricity production (Watson & Rai, 2013).

It is therefore the ultimate aim of this study to bridge this gap in knowledge in order to address the imminent challenges of water and energy insecurity in the wake of the ever-increasing demand for these resources. In order to achieve this goal, this paper will develop a comprehensive link between energy and water, so as to clearly understand where barriers exist in the integration strategy and identify best practice approaches that could be applied to optimally harness this relationship in UK. This will involve assessing the economic and empirical dependence of one on the other.

REVIEW OF PAST LITERATURE

Overview

In recent times, there have been studies and reports integrating the old isolated issues of energy and water under the spectrum of planning, policy formulations, facility designs and operations. Although, research on the interdependencies of these resources only started proliferating in the past few decades, Gleick (1993) concedes that America long realised the need to assess the problems and prospects of this bond, and proactively structured policies and projects to ensure that potential phenomenal challenges to either of the regimes (water or energy) do not uncontrollably impact on the other.

Various universities have also initiated programs to research into the predominant links between water and energy. Regarded as a crucial and unacknowledged linkage, the Australian National University recently launched a collaborative research programme called the Australia-United States Climate Energy and Water Nexus

(AUSCEW), aimed at exploring the water-energy link relative to climate change, and identifying holistic policy recommendations that will help evade adverse impacts of resource insufficiency and favour mutually beneficial solutions (AUSCEW, 2012). More so, in the United States, Harvard University has advanced scientific research on the theme: Energy's growing need for water; targeted at deducing prevailing constraints to sustainable development which lie in the interconnections of individual sectors (SSP, 2013).

Availability and Sustainability

In order to undertake processes that heavily rely on water or energy, there is need to establish the sustainability credential of the resource to be used. Numerous events in different parts of the world serve to underscore the energy and water interdependence in terms of resource availability and sustainability.

A resource may be available but not sustainable; this automatically means that processes reliant on such resource stand to be unsustainable accordingly. For instance, whereas, coal-to-liquid (CTL) plants are extensively water intensive processes, according to reports, china suspended its plans to construct a CTL given its potential long term effect of drought and negative impacts on the quality and availability of the already over-stressed Chinese water resource (Xinhua News, 2006).

It is pertinent to state that in 2005, about 49% of all water withdrawals or 41% of all freshwater withdrawals were used by the US thermoelectric power plants alone (Kenny *et al*., 2005). Consequently, Lake Mead which is the largest reservoir in the US is currently reported to be 100 feet lower than its historic levels, with a further reduction of 50 feet predicted to cause the Hoover Dam hydroelectric turbines to produce very little or even no power; thus placing Las Vegas in a state of critical resource reduction and potential need for cross-border trade, if the water continues diminishing (Webber, 2008).

It will also be recalled that in July 2009, France had to import power from UK. This followed the cooling water temperature remarkably exceeding the permitted discharge temperature of 24°C due to the prolonged heat wave of the nuclear plant which eventually led to the shutdown of 20GW of the 63GW nuclear power capacity of France (Pagnamenta, 2009). Yet, earlier in summer 2003, the same effect of intense heat wave compelled French regulators to grant an official approval which allowed nuclear plants to discharge their cooling water at about 40°C (Siddiqi and Anadon, 2011).

These coevolving relationships have prompted Governments in Countries like US, China, Canada, Australia and Spain to initiate formal strategies to detail this water-energy nexus. The ultimate goals being to develop integrated policies and more robust technologies that will help secure the availability of these resources in the future.

Water Use in Energy Sector

The study on Water Use by Gleick (1993) has been one of the pioneer research efforts which provided an insight into the quantities of water used for various power generation processes, while a detailed set of water use benchmarks for comparing performance in thermoelectric power generation was first published by Dziegielewski *et al.* (2006). Accordingly, the DOE (2006) came up with comprehensive estimates of water use by major power generation types which incorporated contemporary technologies and renewable sources of energy.

An in-depth quantitative analysis of water use requires a clear understanding of the distinction between water withdrawn and water consumed. Water withdrawn means abstracting water from the ground or diverting same from a surface source. On the other hand, water consumed is that "part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock or otherwise removed from the immediate water environment" (Kenny *et al.* 2005, **p.47**). However, water can still be withdrawn and not necessarily consumed. This is regarded as non-consumptive water. The non-consumptive water is withdrawn and returned to its source or near the withdrawal point, although, most often with its chemical, physical or thermal properties altered (Glassman *et al.*, 2011).

Table 1: Consumptive and non-consumptive uses of water *(Hall et al. 2012, **p.70**)*

Consumptive uses of water	Non-consumptive uses of water
Agriculture and irrigation	Environmental regulation
Electricity generation (as cooling)	Hydroelectric electricity generation
Industry and manufacturing	Recreation
Public water supply	Transportation

In the field of energy, the research conducted by Schoonbaert (2012) reveals that the quantity of water consumed in power generation is majorly a function of the generation type, fuel type, cooling technology used for the thermoelectric power generation, or the carbon capture and storage facility (CSF) used in the fossil fuel power plants. A summary of water use by various technologies is depicted in Table 2. The table provides an estimate of water consumption rates for different power generation technologies.

Table 2: Water withdrawal and consumption rates for major power generation sources *(Macnick et al., 2011)*

Fuel Type	Cooling	Technology	Withdrawal (Litre / MWh)			Consumption (Litre / MWh)		
			Median	Min	Max	Median	Min	Max
Nuclear	**Tower**	Generic	5,005	3,637	11,820	3,055	2,641	3,841
	Once-through	Generic	201,619	113,652	272,765	1,223	455	1,818
	Pond	Generic	32,050	2,273	59,099	2,773	2,546	3,273

Natural Gas	**Tower**	Combined Cycle	1,150	682	1,287	900	591	1,364
		Steam	5,469	4,319	6,637	3,755	3,010	5,319
		Combined Cycle with CCS	2,255	2,214	2,300	1,718	1,718	1,718
	Once-through	Combined Cycle	51,735	34,096	90,922	455	91	455
		Steam	159,113	45,461	272,765	1,091	432	1,323
	Pond	Combined Cycle	159,113	45,461	272,765	1,091	1,091	1,091
	Dry	Combined Cycle	27,049	27,049	27,049	9	0	18
	Inlet	Steam	9	0	18	1,546	364	2,728
Coal	**Tower**	Generic	1,932	455	3,410	3,123	2,182	5,001
		Subcritical	4,569	2,273	5,455	2,141	1,791	3,019
		Supercritical	2,414	2,105	3,082	2,241	2,082	2,700
		IGCC	2,769	2,646	3,041	1,691	1,446	1,996
		Subcritical with CCS	1,773	1,628	2,750	4,282	4,282	4,282
		Supercritical with CCS	5,805	5,564	6,042	3,846	3,846	3,846
		IGCC with CCS	5,105	4,992	5,219	2,455	2,373	2,537
	Once-through	Generic	2,664	2,178	3,082	1,137	455	1,441
		Subcritical	165,250	90,922	227,305	514	323	627
		Supercritical	123,144	122,954	123,258	468	291	564
	Pond	Generic	102,696	102,519	102,792	2,478	1,364	3,182
		Subcritical	55,576	1,364	109,106	3,541	3,350	3,655
		Supercritical	81,439	81,189	81,498	191	18	291
Biopower	**Tower**	Steam	68,400	68,173	68,450	2,514	2,182	4,387
	Once-through	Steam	3,991	2,273	6,637	1,068	1,068	1,068
	Pond	Steam	159,113	90,922	227,305	1,364	1,364	2,182
	Dry	Biogas	-	-	-	159	159	159
Hydropower	**N/A**	Aggregated in-stream & reservoir	2,046	1,364	2,728	-	-	-

Sampling part of UK, the abstraction rates for various purposes in 2008 alone, are revealed in figure 1. In England and Wales, a high percentage of water licensed for abstraction is actually not abstracted. According to the UK Environment Agency (2011), a total of 34,500 Ml/d of water was abstracted out of the 75,000 Ml/d of water licensed for abstraction; that is, 46.01% was actually abstracted. Water abstracted for public water supply totalled 46.6% (almost half of the actual water abstracted) although, more than 70% was returned as treated effluent (EA, 2011).

Being a projected quantity, the licensed abstraction is estimated to take care of contingencies or variations in outcome. Thus, it is considered that water used for electricity generation varies according to annual run-offs and could peak in very wet years like 2012. Although it is noted that water abstracted for electricity was 35.35% in England and Wales, but in Wales alone, over 80% of abstracted water is used for electricity generation, while about 15% is withdrawn for public water supply (EA, 2011).

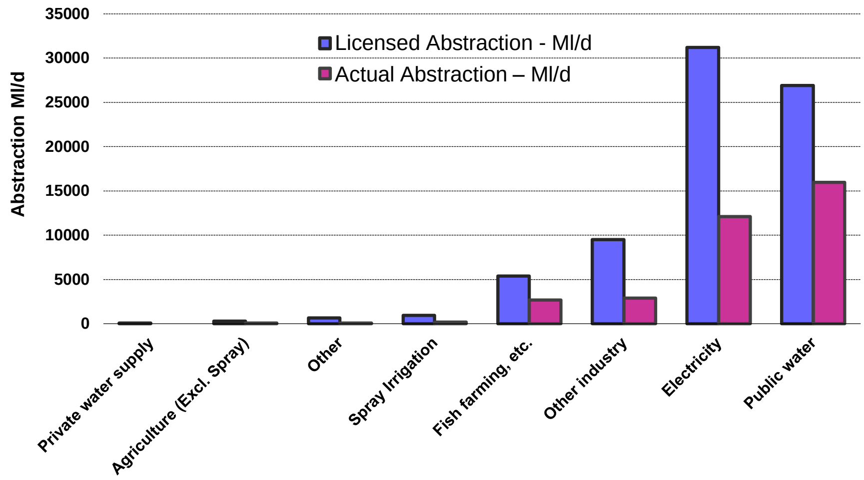

Figure 1: Water abstraction by various sectors *(Source: Environment Agency, 2011)*

Energy Use In Water Sector

Several researchers have variously highlighted the roles of energy in water management. Water abstraction, treatment, desalination and distribution are very energy-intensive processes and these energy implications of water processes are often predicated on the original status (fresh or sea water) and location of the resource.

Concise uses of energy in water processes have been summarised by Watson and Rai (2013) as follows:

- Water abstraction and conveyance: Pumping from source (Ground or Surface) and transfer to reservoir or treatment plant.
- Treatment or purification and distribution of water: Advanced processes such as UV and Ozone applications require greater energy application, while distribution requires lots of energy for pumping.
- Heating, cooling and use of water in facilities for domestic, commercial and industrial purposes; these require varying amounts of energy.
- Wastewater treatments; often requiring highly energy intensive processes to collect, physically segregate, chemically treat, discharge treated effluent and landfill sludge.

Problems and Prospects of the Energy-Water Nexus in UK

As posited by DETR (1998, **p.1**), “Pumping costs UK industry over £1,400 million in electricity each year, mostly for pumping water, and estimates suggest that over 20% of this figure could be saved”. Accordingly, in the food manufacturing sector alone, the water expenditure is approximately £300 million annually, while energy is £800 million and estimates indicate that a 20% reduction in water use could save the food industry £60 million a year (FISS, 2007).

Worthy of note is that the water-energy links vary with the availability and nature of the water resource which is often a function of climate variability. With the Atlantic Ocean bordering Scotland, 70% of the surface area and 90% volume of the water in the entire UK is providentially located in Scotland (Scottish Natural Heritage, 2001). This condition underscores the great hydro potentials of Scotland and has led to the formulation of frameworks and design of strategies to harness the water resource, including its tides and waterways. Typical examples are the Scottish Renewables Obligations (SRO) which is Scottish Government's main means of increasing electricity generation from renewable sources – legislated for in the Renewals Obligation (Scottish) Order 2006 (SI) 2006 No. 1004 (The Scottish Government, 2013); and the recent Scottish Hydro Agenda aimed at harnessing Scotland's vast water resource, advancing water technologies and delivering economic gains (Scottish Government, 2012).

The need to align this water-energy scrutiny becomes even more intensified following the prediction that "by 2030, hydropower will become the world's dominant renewable energy source, providing more than twice the amount of its nearest rival, on shore wind power" (Waughray 2011, **p.10**).

From estimates, hydropower evaporates approximately 17m^3 of water per Mega Watt Hours of energy generated (ADB 2013, **p.14**) and 'UK's energy demand is forecast to increase by 36% between 2011 and 2030 (BP, 2013, **p.4**)', with 15% projected to be supplied from the renewable sources by 2020 (DECC 2011, **p.5**). But the UK with 2650m^3/year of water per person (Kaczmarck, 1995) is already classified as a country with 'low' water availability (Holt *et al*., 2000). Where UK is faced with any spike in water-energy demand, the potential aftermaths may include: cross-border trade or trade-offs, or desalination of sea water.

Thermoelectric power plant cooling takes great amount of water. New technologies such as the combined cycle gas turbine power plants are acclaimed low water intake technologies, yet they end up having higher net water consumption. Also Biofuel use has been considered as a strategy to reduce carbon dioxide emissions and oil import; however biofuel is the most water-intensive source of fuel, and its use in large scale means increasing water consumption in energy production (Mielke *et al*., 2010).

QUANTIFYING THE UK WATER-ENERGY NEXUS

Energy use in water processes

A clear summary of energy intensities of water and waste water treatments has been presented Figure 2. Critically analysing the trend, it is established that except in

2002/03 when energy used in treating 1ML of water slightly rose by 18kWh above that used for treating 1ML of sewage, wastewater treatment energy intensities have remained higher over the other years. Water treatment energy intensities have been on the decline from 2003/04 to 2006/07. It took 559 KWh of energy to treat one Mega litre (1ML) of water and 756 kWh of energy to treat 1ML of sewage in the year 2006/07. Relative to the previous year (2005/06), energy used in treating wastewater increased by 122kWh/ML while energy used in treating water reduced by 27kWh/ML following an earlier drop between 2004/05 and 2005/06 by 77kWh/ML. Sludge aeration has been considered the most energy intensive process in wastewater treatment (Caffooor, 2008).

A major reason for the increasing energy usage in wastewater treatment is the implementation of the stringent WFD quality requirements of 'good ecological status' for UK waters by 2015. The directive according to Watson and Rai (2013) is predicted to cause further increase in the energy intensities of water and wastewater treatment to almost 100%.

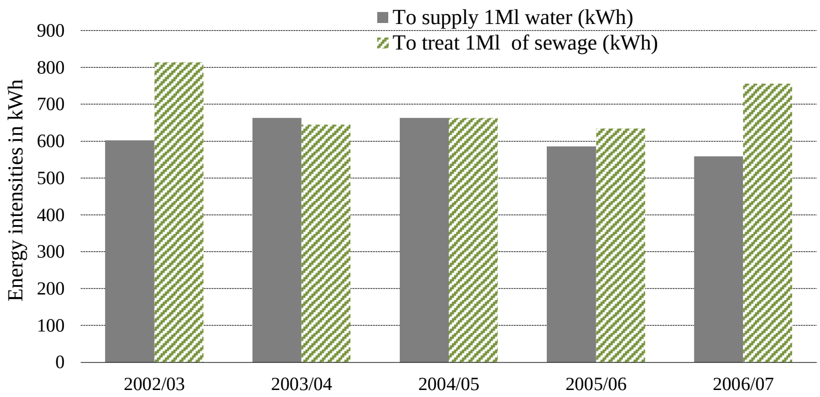

Fig 2: Energy intensities of treating 1ML of Water and Sewage *(Data source: Water UK, 2007)*

Figure 3 indicates electricity generated in UK from major fuel types. Between 1999 and 2011, natural gas constituted the dominant fuel in relative terms, representing 40.04% of all UK energy generation; while solid fuel produced a total of 35.11% of the UK energy. Although the decline in coal usage between 2006 and 2011 may be alluded to the high prices of coal especially relative to gas; however, in 2012 solid fuel accounted for the main electricity generation, with an increase by 53.93TWh above that generated from gas.

From this account, it is inferred that the UK fossil capacity is still high, representing 75.92% of the total energy generation, while, electricity from the nuclear source stood at 22.94%. Nuclear energy has remained less than the 99.49TWh generated in 1998, although it increased by 8.27TWh between 2010 and 2012.

The hydro energy constitutes only 1.14% of the energy generation, while the share of oil has remained insignificant. In a nutshell, the chart shows that UK energy sector is heavily reliant on the Gas, Coal and Nuclear fuel sources, and explores less of the Oil and Hydro sources of energy.

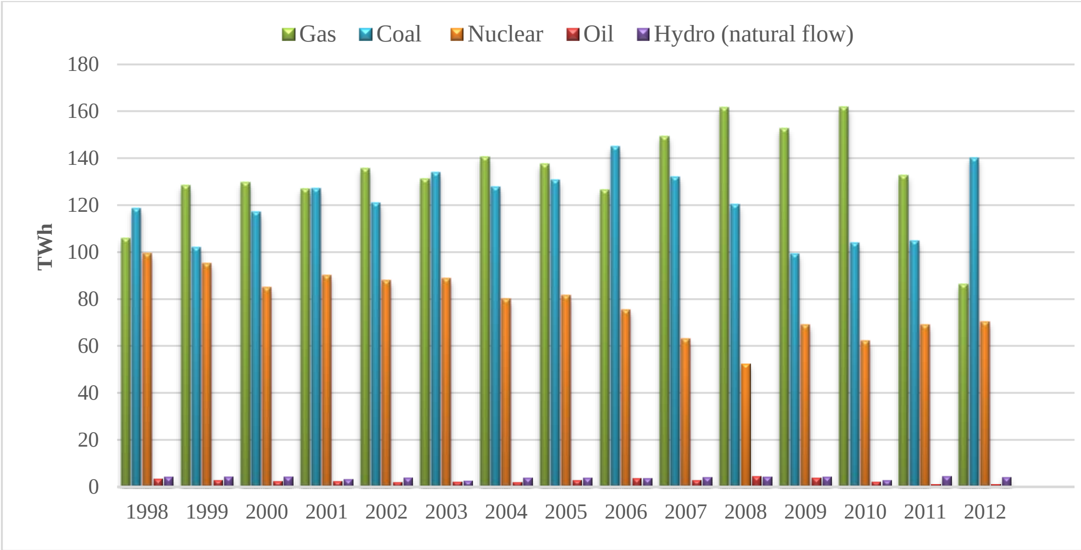

Fig 3: Total electricity generated in UK from major fuel types *(Data Source: DECC, 2014)*

The sharp increases and declines in UK Hydro energy generation from 1998 to 2012 as shown in figure 4, is majorly attributed to external factors such as annual rainfall averages and seasonal variations like heavy rains in winter. From figure 4, it is deduced that 69.95% increase in electricity generation happened between 2010 and 2011, then a 9.24% decrease in 2012 and a further decline by about 13.45% (0.54 TWh) in 2013. The high energy generation between 2011 and 2013 follows the heavy rain in UK during these periods especially in 2012.

Hydropower with a conversion efficiency of above 85% remains a predictable and reliable source of energy in the UK. The hydro resources of the UK can still be further harnessed through extra development of small and micro-scale hydro schemes from municipal to national level.

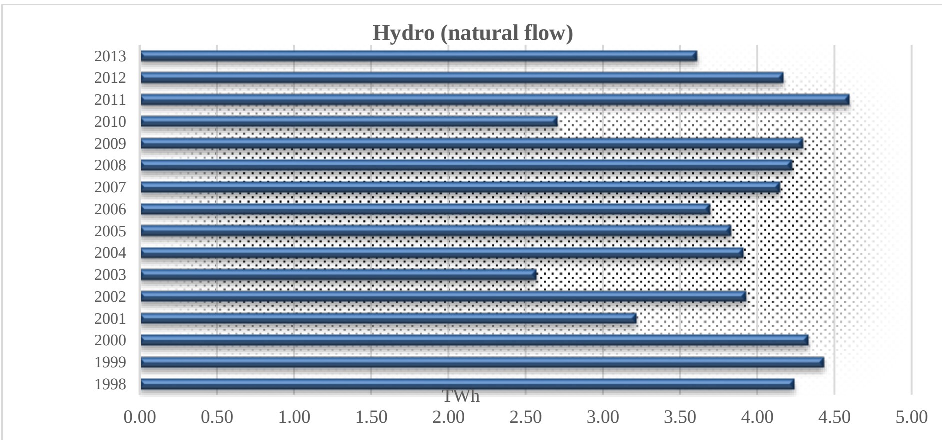

Fig 4: Total hydro electricity generated in UK (1998-2013) *(Data Source: DECC, 2014)*

Figure 5 reveals how UK regions generate their hydroelectricity. It can be seen that the energy generated by Scotland peaked in 2005 totalling 6756GWh, then sharply dropped in 2010. This decline is traced to the average rainfall in UK averaging 952mm in 2010 and increasing to 1331mm in 2012 (Met Office, 2014); this condition is actually consistent with the impact of annual run-off on hydro energy generation.

In Wales, there is a relatively consistent trend in the energy generated. The generation gradually kept increasing from 2004 to 2008, then it started declining, but has risen again from 2011.

The chart therefore shows that Scotland has the highest and growing hydro potential while Northern Ireland has the least contribution to hydro energy generation. This supports the claim that England and Wales has hydro potentials in the range of 146 to 248 MW (British Hydro Association, 2010) while Scotland's hydro potential is in the region of 2,593 MW (BHA, 2008).

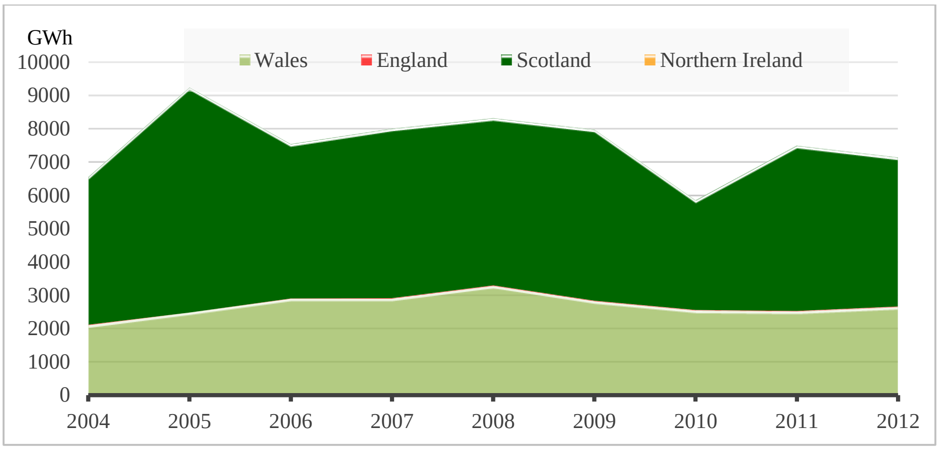

Fig 5: Electricity generation and supply from Hydro flow for Scotland, Wales, Northern Ireland and England, 2004 to 2012 *(Data Source: DECC, 2013a)*

The report by UK Water (2010) reveals that renewable energy generated by water and wastewater companies in the UK totalled 665 GWh in 09/10 relative to the 742 GWh generated in 08/09. This been a downward trend, strongly challenges the goal of generating 15% of UK's energy from renewable sources in 2020. Although, UK has put in place renewable financial incentives through the Renewables Obligation (RO) Scheme which provides renewable electricity generators with financial support more than what they receive from selling same to the wholesale market (The Scottish Government, 2013).

At the moment, UK hydro receives financial support from Government through the RO. It is reckoned that the RO will help reduce the investment cost and boost the overall competitiveness of the hydro technology relative to other established sources of electricity (HM Government, 2009).

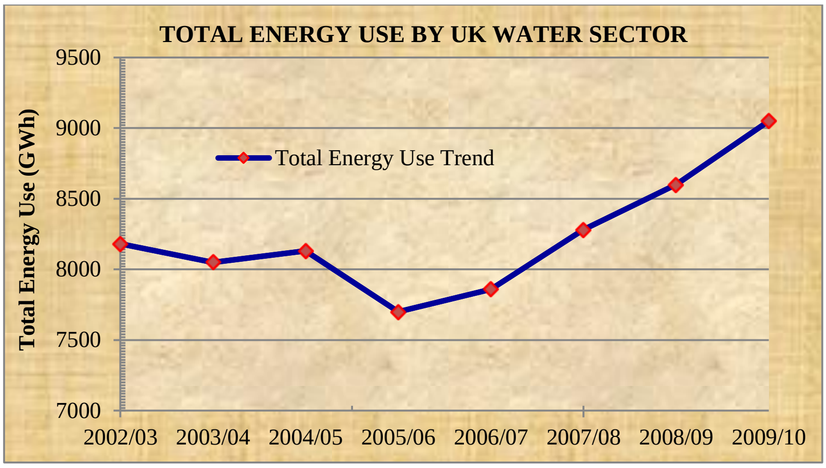

Fig 6: Total energy use by UK water sector (*UK Water, 2010)*

In total, energy use by the UK water sector increased by 4% between 2008/09 (8160GWh) and 2009/10 (9012GWh) with the trend presenting high possibility of future growth in the energy intensities as revealed in figure 6. This energy use is the energy from electricity and gas for water and wastewater pumping and treatment (operational purposes), and for administrative functions, excluding transport (UK water, 2010).

With the increasing stringent quality standards for water and wastewater processes, energy use in the water sector is predicted to keep increasing. However, with the technological advancement in water and wastewater treatment facilities, the industry is set to identify best strategies to reduce this rising energy and minimise or eliminate such negative impacts as GHGs emission.

Water Use in Energy Processes

Figure 7 provides estimates of total licensed abstractions in England and Wales. It shows that for electricity supply, after a 2,525 Million cubic meters increase in water abstraction between 2000 and 2001, the abstraction volume had fallen steadily from 29,571 Million cubic meters in 2001 to 27,471 Million cubic meters in 2006; while from 2007 – 2012, water abstraction volume increased by 7,699 Million cubic meters for electricity supply.

Water abstraction for public water supply had been fairly steady with difference between the highest (in 2005) and lowest (in 2009) abstraction totalling 573 Million cubic meters. Water used in fish farming has drop from 1723 Million cubic meters in 2000 to 974 Million cubic meters in 2012, while industrial water use had relatively reduced after it peaked by 2418 Million cubic meters in 2003.

On the average, 76.03% of the total water abstraction was used for electricity supply, 15.51% for public water supply, 5.20% by industry, 3.15% for fish farming, while 'other' water uses constituted 0.11%. Thus, water abstraction by the electricity sector of England and Wales was the largest, and has continued to grow remarkably.

Whereas, more rainfall leads to reduction in water abstraction for irrigation and fishing, the mark increase in water use for electricity supply between 2011 and 2012 can be attributed basically to 2012 been the second wettest year in UK since 1910, with rainfall average of 1,330.7mm preceding the 1172.5mm of the previous year – 2011 (Met Office, 2014). Reduction in water use in the industrial sector can be linked with the application of more efficient water and wastewater facilities in recent times.

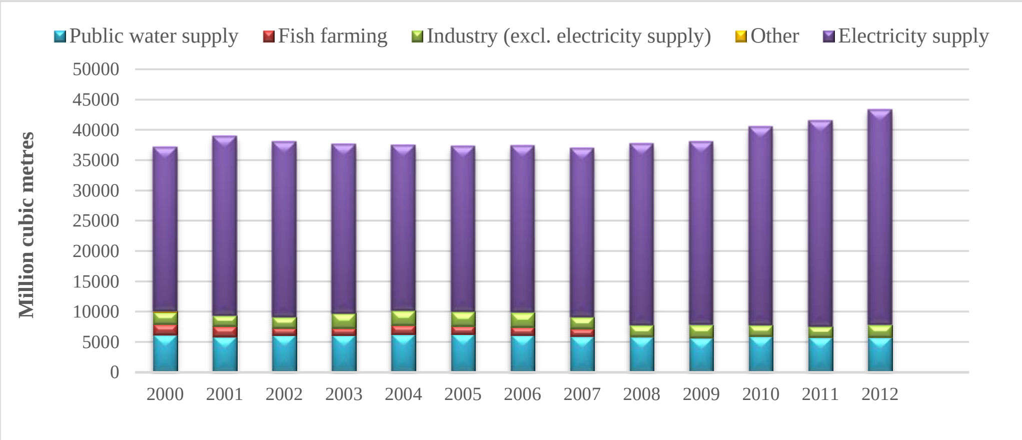

Fig 7: Total estimated licensed abstractions from major sources by purpose, England and Wales (2000-2012) (DECC, 2013b)

SUMMARY AND RECOMMENDATIONS

Results of the water-energy nexus appraisal reveal that energy use in the water sector has intensified by about 10% over the last eight years, with a 4% escalation to 9.012 TWh between 2009 and 2010 (Water UK, 2010). Also, the energy sector's water demand has continued to increase with the nation's growing energy needs, and accounts for approximately 32% of total freshwater abstraction in UK (Watson and Rai, 2013). In England and Wales alone, between 2000 and 2012, 76.03% of the total water abstraction was used for electricity supply, 15.51% for public water supply, 5.20% by industry, 3.15% for fish farming, while 'other water uses' constituted 0.11%.

Scotland's hydro potential should be further harnessed. Cleaner energy sources should be encouraged and incentivised if UK must meet its 15% energy from renewable sources in 2020. Water harvesting and reuse should be highly promoted both at the local and industrial levels, to minimise overall water demand and volume of sewage treated at the wastewater treatment plants.

Accordingly, whereas thermoelectric and nuclear plants take up as much as 90% of fresh water abstracted for energy purposes, and air cooling is relatively not an efficient cooling strategy, the use of a hybrid system (encompassing water and air) will help reduce the water taken up by the energy sector.

There is need for a standard accounting system by both the energy and water undertakings. This will serve as a gauge for measuring the consumption rates of these resources and identifying possible best practices. A department should be created to oversee the implementation of this water-energy integration strategy; this unit should work closely with Ofwat and Ofgem (the UK water and energy regulators respectively) to identify possible problems and prospects of any planning or provision of either the water or energy resource.

An integrated approach to assessing infrastructure sectors will help eliminate any wasteful or unnecessary duplication of ideas and reduce conflicts of interest which are often associated with isolated strategies.

Lastly, further researches on the design of low-energy facilities for water and wastewater treatments should be encouraged.

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