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Water as an economic resource and the impacts of climate change on the hydrosphere, regional economies and Scotland

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Abstract

There is increasing evidence that the global climate is changing and that this will have implications for the future of water resources. The impacts of climate change will be transmitted primarily via the global hydrosphere, whereby changes in rainfall patterns and the frequency and magnitude of extreme weather conditions (e.g., flood and drought) will result in significant challenges, including for the way we access, manage and use freshwater resources. In addition, water demand will continue to rise to support a growing global population and its resultant increases in food and energy needs. There are likely to be variations across the globe in climate change impacts and these will further exacerbate existing spatial disparities in water availability. Water is a critical component for all aspects of life, and is particularly significant in many economic activities (e.g. agriculture, energy etc.). Changes in water availability and hydrological extremes will impact at regional and global scales on economic activity, supply chains, key industries and migration. While all regions of the world will be impacted by climate-induced water stress, regions with robust water policies and water management strategies, or at the leading edge of water-technologies may see opportunities. Here, we discuss the projected impacts of climate change on water resources, and the challenges and opportunities this poses for economic activities in Scotland, including Scotland's readiness to adapt to changes in water availability.

Keywords: Climate change, water resources, economic growth, water policy, Scottish economy

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I Introduction

Water is the most critical natural resource available to humanity. However, water resources are currently threatened by systemic global changes as a consequence of climate change, population growth and urbanisation, and represents one of the world's most critical challenges (World Economic Forum, 2018). As a resource, water is vital to the emergence and survival of societies, ecosystems and economies, and has played a critical role in the development, advance and collapse of civilisations (Sivapalan, Savenije, & Blöschl, 2012). Of the total global water supply (some 70% of the Earth's surface), 97.5% is saltwater (oceans), with only 2.5% freshwater. However of that potable resource, 70% is locked in polar ice-caps, and a further 29%

is located in deep groundwater stores, which are too deep or expensive to access and use. Globally, the potable water supply comes from the remaining 0.01% of freshwater that is readily accessible in lakes, shallow groundwater and rivers, which in turn present a range of accessibility challenges globally. Spatial and temporal disparity occurs globally, with around one-third of the global population lacking access to clean, safely managed water supplies (United Nations, 2018).

Today, as the global population grows toward 9 billion, global water resources are under increasing pressure, not just for drinking water itself, but also for food and energy production, which are significant end-users of water (Kummu et al., 2016; Sušnik, 2015). Increases in demand for water, energy and food are occurring simultaneously with the impacts of climate change, altering the spatial and temporal reliability of existing freshwater resources. The hydrosphere[1] represents a key medium through which the impacts of climate change will be transmitted to all aspects of society, the environment and global economy (Barnett, Adam, & Lettenmaier, 2005).

Climate change presents two vital water-centric challenges: (i) ensuring the global population has access to critical water resources, (ii) mitigating against the risks posed by an increase in frequency and magnitude of environmental hazards such as floods, droughts, storm surges and sea-level rise (Kundzewicz et al., 2018). Although our understanding of the mechanisms of climate change have advanced considerably in recent decades, our readiness to deal with these changes remains a major challenge for politicians, policy makers, water managers and utility providers alike (Azhoni, Jude, & Holman, 2018; Eisenreich, 2005).

The impacts of environmental change will have a profound effect on global and regional economies. Changing resource availability, changing weather patterns, migration of people, and changing patterns of demand for particular goods and services will affect the nature and structure of economic activities in a water stressed future. Many of these changes are already evident. Prolonged periods of drought have significantly reduced available water supplies in Cape Town, and promoted mass migrations to Europe and North America (Missirian & Schlenker, 2017)), while record-setting weather events and destructive climatic extremes - such as the wildfires in California, the floods in Southern Europe and devastating typhoon and hurricane

[1] The hydrosphere, also known as the water cycle, is the movement of water around the Earth's surface, and includes evaporation from oceans, precipitation, water storage (as snowpacks, in lakes, in soils, in groundwater) and runoff from the land and rivers, back to the oceans.

systems in parts of Asia, the Caribbean and North America - are occurring with increasing frequency and magnitude.

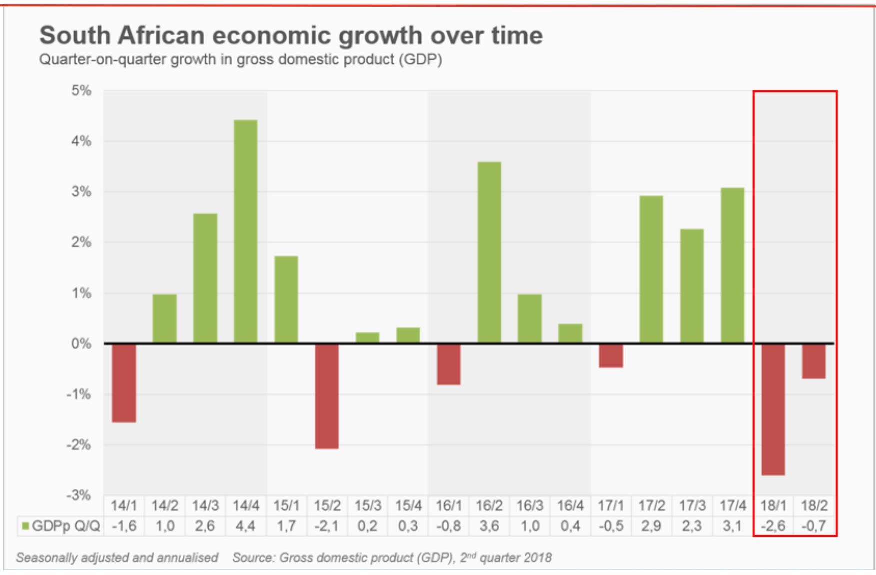
In this paper, we explore the consequences of environmental change for the hydrosphere, and explore what this means for national and regional economic activities. The paper addresses what such changes could mean for the Scottish economy, and provides a series of observations on current trends of water-use within the Scottish economy before concluding with recommendations on how Scotland can best prepare for changing patterns of water availability as a consequence of the future changes to this critical element of the global natural environment.

II Water and the economy

Water has played a critical role in the growth and collapse of ancient economies and is a critical component of contemporary economic activity. According to the World Bank, globally, about 92% of freshwater withdrawals support agricultural activities (including irrigation, drinking water for livestock and cleaning of equipment) (World Bank, 2018). Water is also an integral component of energy generation, especially electricity production where water is used for both steam generation and cooling, as well as directly in hydroelectric power schemes.

The effects of climate change on the hydrosphere has resulted in regional disparity in the availability and uses of freshwater resources, impacting regional economies as a result. Episodic events, such as the prolonged drought in Cape Town earlier this year, highlight the fragility of a disrupted resource on a whole urban economy whose impact was ultimately observed in the macroeconomy (Gallie, 2018). Loss of revenues from water charges, loss of tourism, and significant output reductions in agriculture and horticulture (-33.6% Q1), mining (-9.9% Q1), and manufacturing (-6.4% Q1) resulted in a contraction of the South African economy by -2.6% 2018 Q2 and -0.7% in 2018 Q2 (Figure 1).

Figure 1 South African economic growth rates (quarter on quarter, seasonally adjusted and annualised) from 2014 (Q1) to 2018 (Q2), emphasising the effects of the 2017/18 drought on GDP.



Source (Stats South Africa, www.statssa.gov.za)

Regions that experience chronic periods of drought and low rainfall, while continuing to maintain economic activity, provide useful examples of resilience and adaptive economic behaviours. For example, California is the fifth largest economy in the world ahead of the United Kingdom and France. While its $2.7 trillion economy is bolstered by a thriving tech and entertainment industries, California also boasts significant agriculture, viticulture, tourism and manufacturing industries that are intensive users of water, often resulting in California's exports having an embedded high water footprint[2] (Fulton et al., 2012). Improvements in water management, improved water-use efficiency technologies, the development of water cap and trade markets[3] and enhanced underground water storage facilities have equipped California to weather prolonged droughts while continuing to supply competing economic demands for water. An on-going programme of investment in infrastructure and technological development

[2] A water footprint is the cumulative volume of water consumed across the entire supply chain of a particular product. For a business, individual, region or country, it represents the total water embedded in the goods that are imported or consumed. A water footprint is a multidimensional indicator and captures the type of water used (i.e. "blue water" is from surface or subsurface stores such as lakes, reservoirs or rivers; "green water" is precipitation that is stored in soils, and "grey water" accounts for wastewater and a measure of the pollution associated with a particular activity) in addition to the location and timing of water use.

[3] These markets operate in a similar fashion to carbon trading markets, whereby caps are set on water usage (and pollution levels), and regions with high consumption rates can buy credits from other regions where consumption rates are much lower to offset their own use.

has enabled California to sustain successful economic output in light of challenging environmental conditions (Hanak et al., 2003).

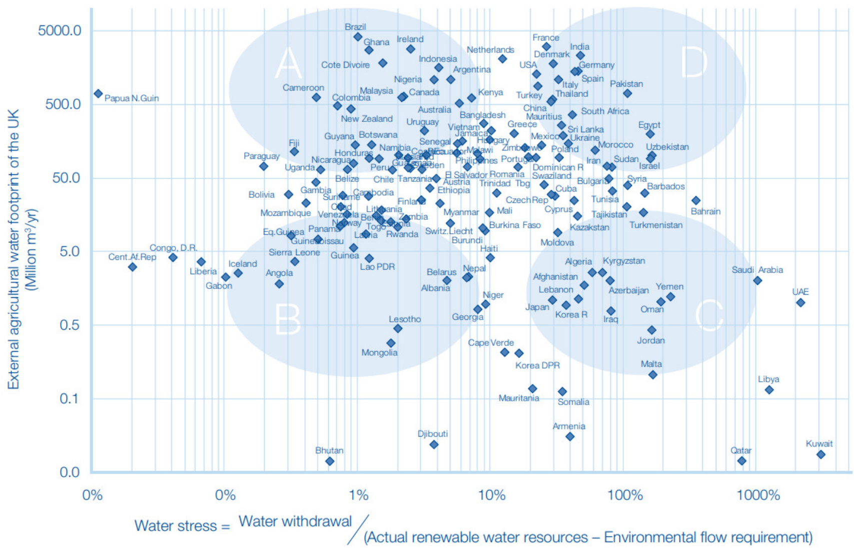
A country's water footprint measures the amount of water use globally which is implicit in the consumption of goods and services at a national level, and includes the water footprint of imported goods (and services). Take the example of coffee, one of the most traded commodities in the world (behind crude oil and derivative products) which is worth $100 billion (US) to the global economy. Coffee beans are grown in over 60 countries across Asia, Africa, Central and South America, and the Caribbean, where a particular narrow climatic range facilitates their ideal growing conditions (Figure 2). As rainfall patterns shift and changing global temperatures impact the migration of pests and diseases, the cultivated area of coffee production could reduce by half (Bunn et al, 2015). The change to rainfall patterns will also reduce the availability of water for crop irrigation, hindering crop yield and quality. This will not only impact the near 100 million people that are sustained by the agro-industry and supply chains of coffee production, but will also result in significant exports of water-intensive products from water stressed regions, impacting on domestic water security. Demand is likely to remain high even as the resource abundance diminishes, and as a result, trade in products like coffee will result in significantly high water footprints for importing countries with high consumption of such produce, in addition to sustaining elevated demands in water marginal countries.

Similar impacts will be experienced across a number of industries that rely on seasonal rainfall or runoff from melting glaciers and snowpacks. For example, agricultural irrigation in California relies on regular melt from snowpacks in the Sierra Nevada mountain range, which have seen both annual reductions in accumulated snow mass, and earlier spring runoff rates due to increased temperatures (Schwartz et al., 2017). Similarly, areas of the South American Andes rely on tropical glaciers[4] as a buffer against highly seasonable rainfall patterns. Climate change has resulted in significant loss of glacial mass in this region, resulting in significant challenges for socioeconomic activities that rely on a regular water supply. Buytaert *et al.*, (2017) estimate that the cities of La Paz (Bolivia) and Huaraz (Peru) rely on glacial melt for around 15% and 19% of their annual total water supply, respectively. During drought years, these contributions can increase to 16% and 27%, with significant increases in monthly contributions during peak drought months reaching 86% and 91%, as more local sources are depleted. While these urban

[4] Tropical glaciers are located high in the equatorial mountain ranges of the Andes (South America), East Africa and Papua Indonesia

conurbations have large water storage capacity in interconnected lakes and reservoirs, rural areas rely on runoff from montane regions and are particularly vulnerable to changing climatic regimes. These are often important agricultural communities, as well as home to large hydroelectric production schemes, meaning that changes in reliable water resources can additionally affect food and energy security for the broader nation as a whole.

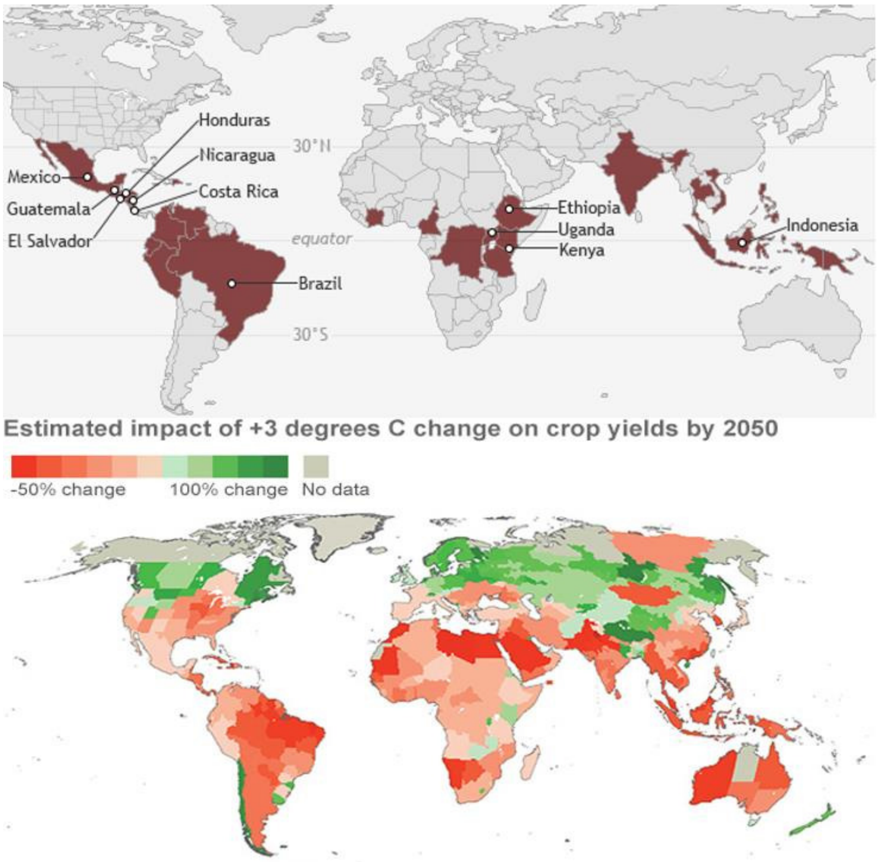
Figure 1: External agricultural water footprint of the UK (million m³/year) and degree of water stress within that country[5].



Source: (Hoekstra & Chapagain, 2006

[5] Group A has a high export footprint to the UK but low water withdrawal compared to available water. Group B countries have low export footprint to the UK and low water withdrawal compared to available water. Group C countries have a low export footprint to the UK but significant water stress, and Group D countries have high export footprints to the UK with significant water stress

Figure 3: Top: Major coffee growing regions of the world (Source: NOAA) and Bottom: project impacts of climate change on crop yields by 2050



Source: World Resources Institute

III Scotland's economy and climate change

Scotland has abundant water resources as a result of its wet maritime climate.[6] Annual rainfall in Scotland averages 1.4 metres per annum. However, total rainfall varies across Scotland as a consequence of the changing elevation gradient from West to East. In Western Scotland, where many rainfall systems arrive from the Atlantic Ocean, annual rainfall in the upland West Highlands can be in excess of 3 metres per annum, while the flatter and more densely populated East Coast can be markedly drier, with around 0.6 metres of rain per annum (Figure 3). As a

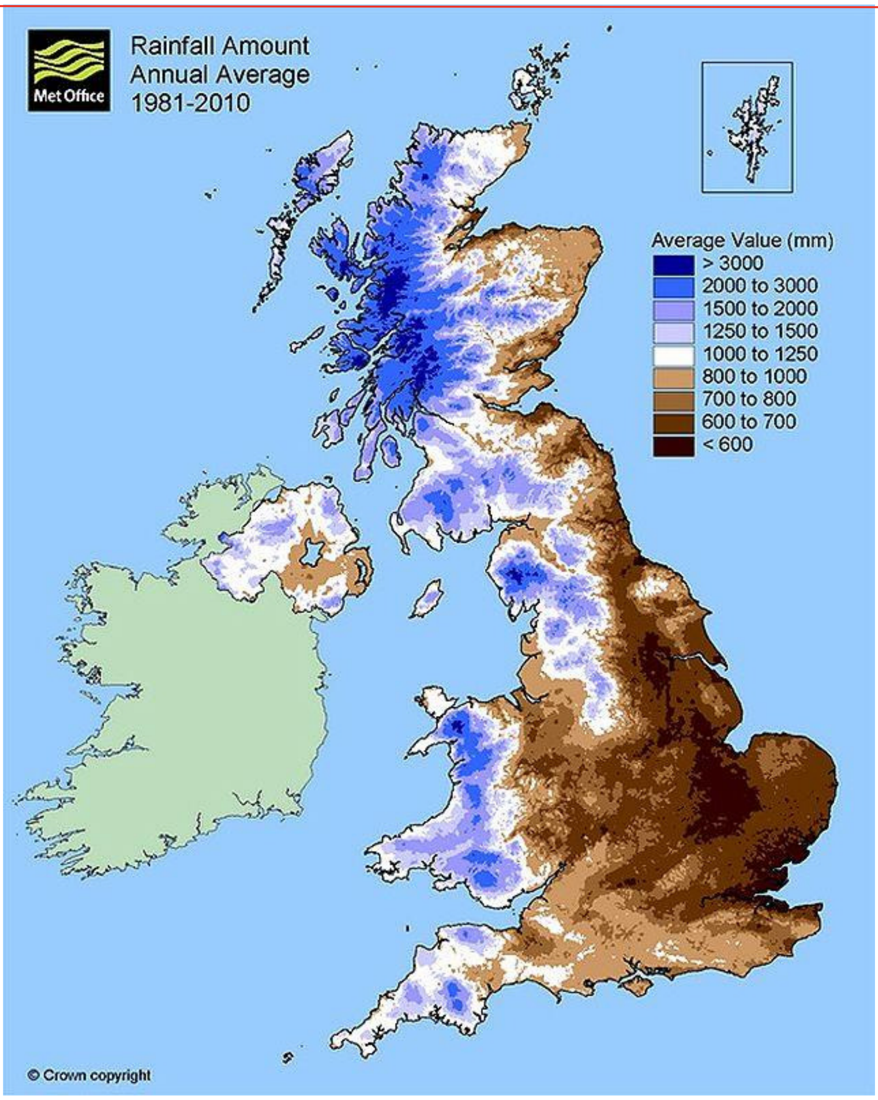
[6] In the Köppen climate classification, Scotland as a Western European country experiences a temperate, oceanic climate (cfb)

result, water distribution is distinctly uneven, and many areas experience a small margin between supply and demand. In addition, there is limited infrastructure to move water from the west (where the majority of the resource is located) to the east (where there is highest demand for the resource) (Scottish Water, 2015). Scotland's overall rainfall has increased since the 1970s, with current volumes around 13% higher than the average values observed during the early 20th century (The Scottish Government, 2014). Furthermore, increasing temperatures during the winter months have resulted in reductions of low altitude snow cover in Scotland (Trivedi *et al.,* 2007), with precipitation falling as rainfall rather than as snow. During the winter and spring, increased temperatures have resulted in both reduced snow accumulation and accelerated rates of snowmelt, resulting in soil moisture deficits into the later spring months when agricultural activities intensify. Warmer temperatures combined with drier summer conditions will result in enhanced rates of evapotranspiration, resulting in water resource deficits occurring during the summer and autumn months (Brown et al., 2012).

Scotland's economic water usage is somewhat atypical compared to other developed countries in that agriculture and energy manufacturing have relatively low water-footprints. In Scotland, most agricultural crops are rain-fed, with irrigation being limited to the East to support potato farming. In the energy sector, the Scottish Government's ambitions to reduce carbon emissions and expand the use of renewable technologies have also had significant consequences for water use. The closure of Cockenzie and Longannet power stations as part of the shift toward renewable energy resources (onshore wind, offshore wind, hydro and wave, which provide 68% of total electricity demand in Scotland) have significantly reduced the volumes of water used in electricity generation in Scotland (Allan et al., forthcoming). The decommissioning of nuclear facilities at Hunterston in Ayrshire (2024), and Torness in East Lothian (2030) will further reduce water intensity in the energy sector.

The abundance of freshwater in Scotland has resulted in a number of economic opportunities for Scotland, with many of our emblematic industrial sectors and brands reliant on freshwater as a critical input. One such emerging and increasingly successful sector is the craft gin industry, of which 70% of UK production is located in Scotland and is worth £1.76 billion to the UK economy (BBC, 2017). The emblematic whisky industry is worth an estimated £4.4 billion to the UK economy, contributing to around 3% of all UK trade. It is also a significant user of water, with each distillery across Scotland using water from streams, lochs, groundwater or piped supply for production and cooling processes. The UK Waste Resources & Action Programme (2011) estimates that the whisky industry uses around 61 billion litres of water per annum, 75-85% of which is used in the cooling process (representing water that is not “consumed”, but returned to the environment under strict quality regulations). This means for every 1 litre of whisky produced, 46.9 litres are used in production and cooling processes.

Figure 4: Rainfall map of the United Kingdom (1980-2010 average) in millimetres.



Source: United Kingdom Met Office

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As a water-intensive product, whisky production is especially vulnerable to periods of dry weather conditions. In 2008, several weeks of dry conditions resulted in production at five major distilleries in Islay being stopped due to water scarcity on the island (Kelbie, 2008). Similarly, dry conditions earlier in 2018 resulted in production being stopped at half of Islay’s ten distilleries. Additionally, the Blair Atholl and Edradour distilleries in Perthshire had to stop production as water flows in the Allt Dour burn dropped to insufficient levels (The Courier, 2018)

Disruption to production is not restricted to changing water availability; dry weather and drought conditions also impact on the growth of crops crucial in the whisky process including barley and maize. The "footprint" of whisky extends globally through its use of imported (non-water) ingredients. For example, some grain used in whisky production originates from outwith the United Kingdom, and so shocks across the supply chain in other parts of Europe can impact on production here in Scotland. While increased temperatures have demonstrably lead to increasing barley yields in parts of the United Kingdom (Yawson et al., 2016), reductions in soil moisture and reduced recharge of groundwater conditions present significant challenges to distilleries across the country. The water intensity of the whisky production process is a major focus for enhanced sustainability within the industry, and both the Scottish Environmental Protection Agency (SEPA) and Scotch Whisky Association (SWA) are committed to improving the water efficiency of distilleries by 10% by 2020 (Scottish Environmental Protection Agency, 2018).

Climate change induced future water-stress will challenge water-intensive economic sectors, either directly (as domestic water resources are impacted) or indirectly (via the impacts of water-stress in regions from where inputs are sourced via global supply chains). The atypical prolonged dry weather that Scotland experienced in the summer of 2018 had a demonstrable impact on the rural economy with soil moisture deficits and limited irrigation capacity hindering crop yields and impacting farm gate prices for crops and livestock (Scottish Government, 2018). Spring barley was particularly badly affected, with yields anticipated to be 10% lower than in previous years, with overall cereal yields forecast to be 6% lower than in 2017, an estimated loss of production of c. 2.6 million tonnes (Scottish Government, 2018). Such conditions are likely to become increasingly familiar in Scotland, with hotter and drier summer conditions, increased heatwaves and drought events, and an increase in the frequency and magnitude of extreme precipitation events being projected by UKCP18's future climate scenarios (UK Met Office, 2018).

The increasing frequency and magnitude of extreme hydrological events (e.g., drought, pluvial flooding and fluvial flooding) present a significant risk of economic damage to land, property and critical infrastructure. As water scarcity during the summer months becomes increasingly prevalent, there will be a need for end-users and water utility providers to ensure a preparedness for spatial and temporal disparity in water resource availability. For some industries, these projected changes present very real challenges that will disrupt economic output. Natural irrigation via precipitation may significantly diminish and there may be a need for agroindustry to utilise larger volumes of water to irrigate critical crops and provide drinking water for livestock. The whisky industry will increasingly be at risk from the dry summer conditions, with a growing number of distilleries being impacted by water shortages. Finally, the growth in seasonal tourism may place a significant strain on service industries at a time of the year when water availability is at greatest risk.

Global water scarcity is uneven, with certain regions being particularly adversely impacted by future changes in water availability. Water as a resource is too heavy to ship internationally as a manner of addressing this scarcity. In order to reduce the impacts of water scarcity, the mobilisation of labour, economic productivity and international trade away from water-stressed regions to water abundant areas are viable solutions (Debaere, 2014). This would permit water-scarce nations to focus on the most economically profitable activities and import water-intensive products from more water-rich regions when continued production becomes increasingly difficult as water becomes less readily available.

As a result, while there are potential major consequences of climate change for the Scottish economy, current water abundance suggests that there may be economic opportunities with careful management and sustainable practices around our current water resources. The Scottish Government's drive toward carbon reductions and a focus on renewable energy technologies have secured some of our water resources for alternative uses that support other aspects of economic activity. In addition to pioneering green policies, the increase in renewable energy generation represents an opportunity for increased renewable energy exports to the rest of the UK. As the climate of Scotland becomes warmer, there is scope for the expansion of agricultural production into new crops that may currently be primarily imported from much warmer regions. An awareness of the impending changes to our water resources also presents an opportunity for Scotland to pioneer behaviours that would futureproof our water resource infrastructure, upgrading many of the inefficient and dated systems that supply water to end-users to be resilient to future climate change. Finally, water provides Scotland with a comparative advantage to attract new industries that are intensive water users, and are perhaps geographically located within water-stressed areas where the availability or cost of water can restrict particular activities. A 2007 report from WaterWise (a UK NGO aiming to reduce water consumption) highlighted the water intensity associated with some critical manufacturing industries: the production of a single computer microchip can use 32 litres of water, whilst the manufacture of a car can use up to 400,000 litres of water (Zygmunt, 2007). Scotland already has a number of successful technology firms, with the sector concentrated in Edinburgh, Glasgow and Dundee contributing c.£2.8 billion GVA in 2017 (Tech Nation, 2018). The ability to attract water-intensive manufacturing industries (both traditional and advanced) to Scotland presents a significant opportunity to expand the technology sector in Scotland and provide opportunities to create an expanded, highly-skilled workforce across these areas.

IV Preparing for a water-scarce future: next steps

Climate change is already having a profound global impact, and national governments are increasingly taking action to reduce the impacts of changes on critical freshwater resources. To tackle this, and "future-proof" our socioeconomic reliance upon Scotland's apparently abundant water resources, there is a pressing need to better understand our relationship with water, and identify key ways we can improve efficiency. This final section assesses the role of policy, technology and behavioural change can have to help socioeconomic actors better prepare for a water-scarce future.

Policy

A major focus for the development of a water-resilient society is the creation and implementation of policies at both the government and institutional levels (including environmental regulators, utility companies and private businesses) that seek to reduce unnecessary losses through inefficient use of water or leakage. Maximising the benefits presented to Scotland from water resources is a key aspect of the Hydro Nation strategy, established by the Scottish Government in 2012. The policy promotes sustainable practices across the economy to lower water intensities, builds pioneering water research and knowledge-building amongst Scottish institutions around water-centric themes, and provides funding for initiatives and facilities that can improve Scotland's domestic water landscape. As the sole water provider in Scotland, Scottish Water loses c. 500 megalitres per day (Ml/d) from its distribution network; this represents around a third of its total water resource. Identifying and managing leakage from the network is a key strategy for Scottish Water and a critical part of its infrastructure repair policy. A key part of Scotland's resource preservation strategy has been the development of the Scottish Environmental Protection Agency's *One Planet Prosperity* regulatory strategy, that seeks to both help Scottish businesses reduce their water, carbon and material resource consumption and limit their pollution and waste generation (Scottish Environmental Protection Agency, 2016).

Indeed, a critical part of most company strategies is the reduction of emissions, material consumption and water consumption (particularly in water-intensive industries, such as the whisky manufacturing sector).

Floodwater often results in devastating economic losses through damage to property and infrastructure, and there is a significant need to consider the expansion of existing floodplain planning legislation to account for increasing climate change impacts on fluvial flood magnitudes and frequencies.

Non-water policies can also impact significantly on the consumption of water resources. For example, as part of achieving their Climate Change (Scotland) Act 2009, the Scottish Government has already taken significant steps to preparing Scotland for a water-scarce future, by moving toward ambitious renewable technology goals that has resulted in “drying” the energy sector. Systematically replacing water-intensive fossil fuel and nuclear energy power plants with renewable technologies such as onshore and offshore wind turbines, wave and hydropower energy has achieved significant water reductions, as well as carbon emissions (Allan et al., forthcoming).

Technology

Reducing the water that is used unnecessarily in domestic and non-domestic activities is critical to conserving overall water resource for future uses, and technological innovation is integral to achieving this. Simple adaptations such as low-flush toilets and sensor-based low-flow taps reduce water use volumes both at home and in workplace and leisure settings, and both are increasingly replacing traditional bathroom fittings (particularly in new developments). Furthermore, certain industries are investing in new technologies that reduce water consumption in traditional, water-intense activities. For example, laundry services have increasingly adopted low (or zero) water washing machines that rely on polymer-based systems, something that could significantly reduce the water consumption associated with critical economic sectors such as hotels and accommodation, restaurants and industrial cleaning.

The development of environmental sensor technology is vital to future-proofing our future water resources. While space and airborne earth observation (e.g. remote sensing satellites, radar, LiDAR) technologies can provide oversight of our natural resources at a world region and national scale, increasingly “individual” technologies can help to monitor and reduce water waste at a household, or site-level. The increasing deployment of “smart” water meters, which enable the monitoring of water distribution and consumption efficiency have been successful in reducing water consumption in households. For water utility companies, the development of a smart grid network of meters connected to the Internet of Things (IoT) enables real-time monitoring of consumption, facilitating easier billing of customers and faster identification of leaks and hot spots for water waste. However, the overall uptake of smart water metering in the UK has been slow, in spite of the growing evidence of savings that such devices can achieve. This highlights that technology alone is an insufficient strategy to reducing water use, and that a focus on behaviour change is necessary. Paradoxically, water efficiency and savings strategies can result in an increase in consumption, where reductions in water costs via more efficient technologies can result in a *rebound effect* as users end up using more water in new areas. This has been reported in agriculture where more efficient irrigation technology has resulted in the expansion of cropped areas, ultimately resulting in an increase in overall water usage (Sears et al., 2018).

The development and installation of leakage detection systems are powerful strategies for water operators in maintaining efficient systems that supply entire towns and cities. Technological advances have reduced costs, enabled widespread deployment and “live” monitoring, and increasingly resulted in “non-destructive” technologies that can remotely detect failures without disrupting operations and necessitating large-scale disruption in digging up mains supply pipes (Liu & Kleiner, 2013). These types of technologies and applications are particularly important in older urban areas – such as in Scotland - where water and drainage infrastructure are often centuries old and not designed to sustain contemporary demand patterns or rainfall dynamics.

With markedly wet winter months that often result in persistent rainfall and consequent flooding, there is scope to explore using permeable areas of land for intentional flooding, allowing groundwater recharge and subsurface storage of water (i.e., “groundwater banking”, which is common practice in places like California), ensuring that floodwater can be viewed as a resource, rather than an economic cost.

Finding ways to reuse wastewater (‘grey water’) is increasingly a focus for water utility, local authority and national governments (e.g., toilets at the Scottish Parliament use greywater harvested from the building’s roof). Wastewater is a sustainable freshwater resource, and treatment and reuse is increasingly being applied across a number of industries and increasingly, to meet domestic demand. In Turkey, pressures on finite resources from climate change, urbanisation and population growth have already placed a significant stress on renewable freshwater resources, and Maryam and Büyükgüngör, (2017) highlight that by 2025, expected demand will be 183% of current consumption. Wastewater recycling is an option for many countries (particularly where scarcity and looming demand growth is an immediate reality), but existing treatment infrastructure and – crucially - public acceptance are often insufficient to justify the significant overheads associated with creating recycled potable water.

Behaviour change

Technological options only represent one part of the challenge to meet future water demand. Two key issues remain: a “true(r)” valuation of our water resources and facilitating large-scale consumer behaviour change. Valuation of water is a long-standing challenge for water resource managers and utility companies, and necessitates robust monitoring of water resources to identify where, how much, how efficiently water is being used. From the consumer’s perspective, smart meters can facilitate behaviour change and reduce bills. For example, a natural field experiment in Sydney, Australia highlighted a c.7% reduction in water consumption amongst smart meter households (Davies et al., 2014).

Garrick et al., (2017) outline a number of challenges for valuing water resources “appropriately”, i.e. in a way that encompasses contrasting socioeconomic, environmental and cultural values attached to water. In Scotland, water charges are included as part of domestic Council Tax bills along with wastewater services and there is often a perception that water in Scotland is “free” (as well as plentiful). This free water dialogue dominated recent consultations around the provision of drinking water from business premises across the United Kingdom (Keep Britain Tidy & Centre for Social Innovation, 2017). The abundance of water in Scotland, combined with the lack of separate water and wastewater billing services (unlike in the rest of the United Kingdom) can result in complacency around how we value and use our water resources, though the attitude of water as a “free economic good” is widely held across the UK. A YouGov survey in 2014 highlighted that 33% of respondents in the UK admit to leaving the tap running while brushing their teeth, while the figure in Scotland is significantly higher at 47%. In contrast, in California, advertisement campaigns and school programmes during the 1980s that continually reinforced the message of unsustainable freshwater household practices, including turning off taps whilst brushing teeth, has resulted in the practice almost disappearing, while it remains alarmingly common in Scotland.

Implementing behavioural change is a complex area, yet recent policies in the UK have transformed some day-to-day activities. Perhaps the biggest success story is the introduction of the 5p charge for plastic carrier bags introduced by most supermarkets and retail outlets. This has resulted in a significant reduction (80% in Scotland) in the use of disposable plastic bags since its introduction in 2014. Similarly, the coffee chain Starbucks recently introduced a coffee cup levy of 5p per disposable cup, introduced after a trial period in its London stores resulted in a 126% increase in the number of customers using reusable cups (Starbucks, 2018). Price elasticities associated with water tariffs have a demonstrable impact on overall rates of water consumption (Veck & Bill, 2000). Increases in water tariffs are often viewed as socially unjust (hitting poorer households hardest) and with questionable effectiveness, as international results have demonstrated that a 10% increase in the price of water will result in a 1-1.8% reduction in water consumption (Brick et al., 2017). By contrast, using "green nudges" in the form of *social norm*[7] messaging that informs users of their consumption of a resource compared to others in their neighbourhood, results in an increasing awareness and lowering of consumption (Brick et al., 2017), and evidence from the United States has shown a 4.8% reduction in overall water consumption (Ferraro & Price, 2011). Using price signals to nudge consumer behaviour may have some impact in altering perceptions about water and its value in society, however the use of environmental nudges may also have significant impacts without potentially increasing the cost to low-income consumers. Indeed, emphasising the benefits of water-conservation to a population that views water as a bountiful resource represents a unique challenge, but one that may enhance sustainability over time and preserve our most critical of resources for future generations.

V Conclusions

The growing pressures on freshwater resources presents a significant challenge to water utility companies, national governments and river catchment managers. As climate change alters the volume and spatial regularity of water availability, an increased demand from households and non-domestic users presents a *perfect storm* not just for water resources, but also energy and food security. Water is the most critical natural resource in economic activities, and sensible management is needed both locally and globally to reduce the vast transfers of embedded water between countries and ensure local water security is maintained, particularly in water-scarce

[7] Social norm messaging provides users with an overview of their own consumption of a particular resource, often via a smart meter system or SMS messaging system, providing a comparison to the average use within their neighbourhood, driving *pro-social* and cooperative behaviour, particularly when positive behaviour is socially recognised (Brick et al., 2017).

regions. Scotland's wet, maritime climate and abundant water resources places it in a uniquely secure position to prepare for future changes in water resource availability. As a result, economic opportunities will emerge for Scotland, yet as the summer months of 2018 demonstrated, negative economic consequences still feature when water resources are impacted by climatic shortfalls in typical water availability. It is imperative that utility managers, policy makers and end-users of water take steps to protect these resources against future environmental change. This challenge requires a combination of robust climate and water policies from national and regional governance and the adoption of new technology to better monitor water supply and demand. However, there is also a challenge for end-users; to modify their own behaviour around water consumption, particularly in regions like Scotland where water is evidently abundant currently. Behaviour change represents a key challenge for Scotland, especially as water is too often undervalued or taken for granted by users who have rarely encountered scarcity during their lifetime. Changes in price tariffs can positively influence consumption of resources such as water, but research also demonstrates that social norm nudges can also positively influence consumptive behaviour. This combination of policy-technology-behaviour change presents an opportunity to ensure that Scotland has a secure water-future, but also one that yields economic opportunities for new industries and supply chains accordingly and sets Scotland up as an example of a water-rich nation with progressive policies that seek to both utilise and conserve our water resources.

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