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Portfolio Analysis Using Water Shadow Pricing: How Valuing Water Risk Can Reduce Carbon Emissions

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Abstract

Limiting carbon emissions is often the priority for investors wanting to reduce the environmental risk and impact of their portfolio. However, water is a factor that is frequently overlooked in terms of cost to both companies and the environment. Few investors have attempted to value a company's exposure to water risk, and consequently even fewer have suggested the link between water risk and carbon emissions in a portfolio. By using a total economic value framework, the model analyses the total cost of a company's water use, or water 'shadow price'. This goes beyond the price or tariff paid for water and estimates all related internal and external costs, as well as reflecting a company's exposure to water stress. Company carbon emissions were then incorporated into the model, which was used to analyse the total water risk and carbon emissions of all companies in the FTSE100. The analysis shows that a portfolio of all FTSE100 constituents, that has been optimised to reduce carbon emissions, also showed a small reduction in water risk. However a similar portfolio, that has been optimised to reduce water risk, shows a comparable reduction in carbon emissions. This study therefore provides an implementable method for integrating water risk into an investment strategy. It further concludes that the two targets of reducing a portfolio's carbon emissions and water risk are neither difficult to measure nor mutually exclusive.

Keywords:

Corporate water use; Water scarcity; Water shadow pricing

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List of Acronyms

ESG	Environmental, Social and Governance
WRI	World Resources Institute
TEV	Total Economic Value
SEDAC	Socioeconomic Data and Applications Center
DALY	Disability Adjusted Life Year
GDP	Gross Domestic Product

1 Introduction

1.1 Research Context and Knowledge Gap

Without increased efforts on global mitigation, climate change is expected to cost up to 20% of the global economy, every year (Stern, 2007). Water is the primary vehicle through which the effects of climate change will be felt, with a two degree scenario expected to severely decrease water resource availability for an additional 15% of the population; by 2040, 35% of the global population is expected to live in areas of high water stress (Schewe et al., 2014). Costs associated with companies not having access to sufficient water resources are estimated to be around $4trn in 2018 (CDP, 2016).

Some investors include this kind of non-financial information into investment strategies, typically as the environmental dimension of environmental, social and governance (ESG) strategies. However, there is much debate over how ESG information is incorporated, why and to what effect. Consequently, some aspects of ESG analysis receive more attention than others, as is the case with carbon emissions, compared to water risk. A company's levels of carbon emissions and water withdrawal are both common factors in the 'environment' element ESG analysis. However, this assumes that water withdrawal is a sufficient representation of the costs of water use, both to the company and the environment. In actuality, the level of water withdrawal alone ignores numerous factors related to water risk, including the cost of using that water at the expense of other users (such as agriculture and residential use) and the company's exposure to water stress. Many tools have been developed to assist companies in assessing water risk, although these do not go far in explicitly valuing water risk, and are not generally designed for the use of investors.

1.2 Purpose and Research Objective

This study will build on the work done by Ridley and Boland (2015) and Park et al. (2015), by using water shadow pricing to calculate the total water risk cost in a portfolio. In quantifying this water risk, it should then be possible to understand the individual contribution of companies on the total water risk in a portfolio. These companies can then be compared to those companies with the greatest contribution to carbon emissions. This study will therefore have two research objectives: firstly, to develop a practically applicable framework for measuring water risk and incorporating it into portfolio analysis; secondly, to analyse whether reducing the carbon emissions in a portfolio also reduce this water risk.

ESG integration has become a higher priority to investors given recent studies linking ESG performance and carbon emissions with financial returns (Kruger, 2015; Lewandowski, 2015). The current study will therefore serve as a suggestive insight into the improvement of ESG integration and will aim to further the development of research into water shadow pricing. The results should serve to encourage investors and researchers to investigate water risk in investment strategies more thoroughly. The study also advocates recognising water risk not just an ethical responsibility but also a financial one.

1.3 Content and Structure

This study is structured as follows: Chapter 2 provides a brief overview of water stress and climate change and the resulting impacts on companies; it also investigates the existing attempts to assess the financial value of water risk, and reviews the existing literature on integrating ESG into investment strategies. Chapter 3 outlines the methodological framework, both for using shadow pricing to financially assess corporate water risk, as well as for applying physical environmental risk factors to investment strategies. Chapter 4 presents the results of the analysis, demonstrating what the expected water risk cost of a portfolio is, and how the carbon emissions and water risk of a portfolio can be minimised, subject to certain constraints. It also discusses the implications of the analysis, including how the analysis can be expanded by and the limitations be improved upon by further research. Chapter 5 draws conclusions from the results and endorses how the analysis can be used to enhance the environmental component of ESG integration.

2 Literature Review

This literature review consists of the following four parts: firstly understanding the science of water, carbon emissions and climate change. Secondly, how the science relates to the risks presented to companies. Thirdly, the models that currently exist are compared for the purpose of integrating water risks into an investment strategy. Finally, there is a review of the literature pertaining to the methods and effectiveness of integrating environmental information into investment strategies.

2.1 The Science of Water, Carbon Emissions and Climate Change

2.1.1 Water

Of the total global water supplies, 97% is salt water (NOAA, 2017). Of the remaining 3%, the majority (83%) is frozen, in Antarctica, the Arctic and glaciers around the world, leaving 0.5% of the world's water for ecosystems, and humanity (Lambooy, 2011). Growing water contamination may soon mean that less than 1% of total global water supply is available as freshwater (Freyman et al., 2015). Figure 1 demonstrates some of the properties of water make it uniquely fundamental to sustaining life, such as serving as a universal solvent, coolant and stabiliser of air temperatures and climate patterns (Freyman et al., 2015). Unlike, or at least more so than, most other commodities or natural resources, water is 'tied to bigger issues of social, community and economic well-being' (Freyman et al., 2015:p17). Water is needed to support all aspects of human existence, and its use must be prioritised to fairly meet the needs of growing populations, agriculture, and energy production, whilst minimising the impact on ecosystems (Gassert et al., 2014).

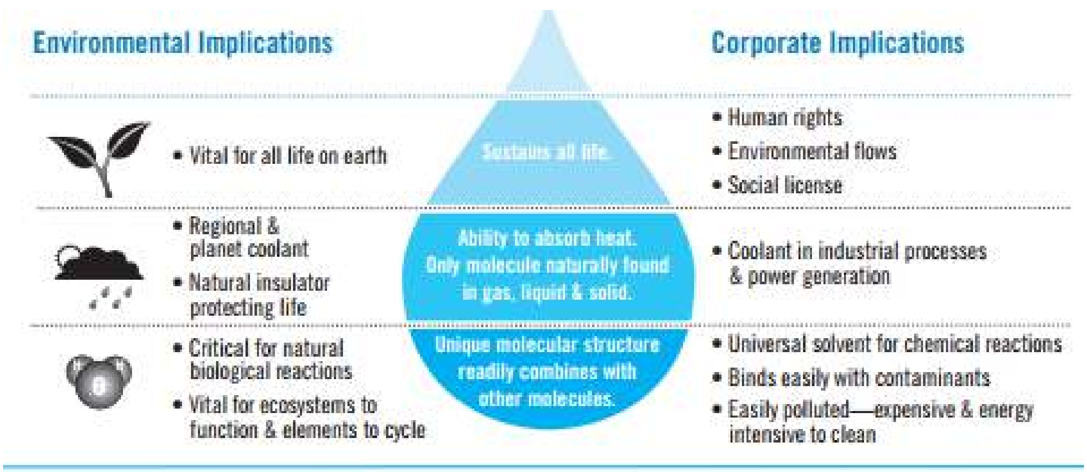

Figure 1: Water's unique properties. Source: Freyman et al. (2015)

2.1.2 Water Risk

In order to identify water risks, it is necessary to measure supply and demand. Gassert et al. (2014) assess water supply in two ways: total blue water and available blue water. Total blue water is an approximate measure of naturalised river discharge; available blue water is an approximate measure of the availability of surface water, excluding upstream water consumption. Water use or demand can similarly be assessed in two ways: water withdrawal and water consumption. Water withdrawal is defined as the 'total amount of water abstracted from freshwater sources for agricultural, domestic and industrial uses' (Gassert et al., 2014:p4). Water consumption is defined as the proportion of water abstracted from freshwater sources that is no longer available for downstream use, due to evaporation or incorporation into a product.

Together, water use and supply data can be analysed to provide different measures of water risk. The World Resources Institute (WRI) uses six indicators of water risk in its Aqueduct Global Maps tool, which are shown in Table 1.

Indicator	**Definition**
Baseline water stress	The ratio of total annual water withdrawal to average annual available blue water. Also known as 'relative water demand'.
Interannual variability	The variation in natural water supply between years.
Seasonal variability	The within-year variation of water supply.
Upstream storage	The number of years of total upstream blue water storage capacity.
Return flow ratio	The ratio of non-consumptive use, both upstream and within catchment, to the mean available blue water.
Upstream protected land	The proportion of total blue water originating from protected areas.

Table 1: Indicators of water risk. Source: Gassert et al. (2014)

Hoekstra (2014) defines freshwater scarcity as including both the physical aspects (with groundwater tables, river flows and lakes all declining, plus increasing levels of water pollution) and the non-physical aspects (such as supply and treatment costs, intermittent supply and conflict over water use). Pedro-Monzonís et al. (2015) take a similarly broad view of water scarcity, in understanding that it relates to all aspects of restricted availability to water. Whereas the EU (2007) defines water scarcity as a scenario in which water resources are insufficient to meet long-term requirements, Loon and Lanen (2013) define water scarcity as the over-exploitation of water resources that arises when demand exceeds availability.

Baseline water stress is a commonly used indicator of the level of competition for available water, and also of the degree to which freshwater is an ongoing concern (ISciences, 2011). Reig et al. (2013) expand this definition to specify the implications of baseline water stress: where total water withdrawals account for more than 20% of available blue water, risks to companies include stress to the environment, increased competition and variations in supply; where withdrawals account for more than 40% of available blue water, risks include conflict between users, issues with water allocation permits, as well as new water resources becoming more costly.

2.1.3 Changes in Water Supply and Demand

Water availability is becoming increasingly constrained, from both the demand- and the supply-side. In terms of supply, water sources are used unsustainably, and are at risk from ecosystem degradation; this is compounded by changing climate patterns increasing the frequency and severity of droughts (Ridley and Boland, 2015). In terms of demand, population growth affects not just household but agricultural water requirements (Ridley and Boland, 2015). By 2030, the global gap between supply and demand for freshwater is projected to be 40% (2030 Water Resources Group, 2009). Where efforts are made to improve access to water, such as in efficiency, storage and infrastructure, it is likely that these improvements will result in increased demand and production, rather than reducing the pressure on freshwater sources (Hoekstra, 2014).

Total freshwater withdrawals have increased by around 1% per year between 1987 and 2000 (WWAP, 2014). The majority of this increase comes from developing countries, suggesting that either developed countries are either improving water efficiency, or are importing water intensive products such as food (Gleick and Palaniappan, 2010) and other commodities (Hoekstra, 2014). Freshwater withdrawals are generally measured across three sectors: agriculture, industrial and domestic, which respectively account for 70%, 20% and 10% of withdrawals globally, although this varies from country to country. In developed countries, the industrial sector takes a greater proportion of withdrawals, whereas in developing countries the agricultural sector uses more, with agriculture accounting for 90% of water withdrawals in least developed countries (WWAP, 2014).

Water demand is expected to grow for all sectors, with most of this demand continuing the trend of coming from developing countries. Demand from the agriculture sector is expected to increase by 20% to 2050. Growing demand from industrial and domestic sectors will also be expected, particularly from cities and countries experiencing accelerated economic growth and sustainable development (WWAP, 2014). Global water demand in terms of water withdrawals is projected to increase by some 55% due to growing demands from manufacturing (400%), thermal electricity generation (140%) and domestic use (130%) (OECD, 2012).

2.1.4 Water and Climate Change

There is a 90% chance of the world warming by two degrees by 2050 (IPCC, 2014). As a result of the increased concentrations of carbon dioxide equivalent gases in the atmosphere, weather changes such as more extreme global temperatures, rising sea levels, and flooding and drought, can be expected to increase (IPCC, 2014; Hoekstra, 2014). Not only are many of the changes in water supply attributable to climate change, but water is also the fundamental link through which climate change will impact humans and the environment (IPCC, 2014).

Climate change exacerbates existing challenges in freshwater supply. Water cycles accelerate and intensify, droughts are longer and drier, and precipitation and flooding are both more frequent and heavier (IPCC, 2014). A two degree scenario expected to severely decrease water resource availability for an additional 15% of the population, and increase the number of people living under absolute water scarcity by 40% (Schewe et al., 2014). Higher temperatures and carbon levels in the atmosphere also increase the likelihood of mega-droughts, which can last for decades (Cook et al., 2015). In dry seasons, increasing climate variability will reduce available water; higher temperatures and compensation necessary for lost precipitation will also increase water demand (Hoekstra, 2014).

A key example of the link between climate change and water scarcity is California's 2013-2015 drought which has been linked to deforestation in the Amazon rainforest (Medvigy et al., 2013). This deforestation has caused an increase in dry air over the Amazon, which can reach the Western Coast of the USA, reducing the Sierra Nevada snowpack and limiting a crucial water source for cities and farms in California.

Several studies highlight the effects of climate change mitigation on water demand: bioenergy crop irrigation can significantly increase demand for water (Mouratiadou et al., 2016; Hejazi et al., 2014), as can cooling systems for low-emissions technologies (Mouratiadou et al., 2016; Kyle et al., 2013). Other important technologies such as carbon capture and storage, as well as many renewable energy sources, require stable supply and significant amounts of water (WWAP, 2014; EIA, 2014). However, mitigating water risk can also increase carbon emissions: desalination technologies can have high energy footprints, potentially increasing carbon emissions (Cornejo et al., 2014).

2.2 Corporate Water Risks

Freyman et al. (2015) divides corporate water risk into three components: risk mitigation, water dependency and water security. Risk mitigation approaches are applicable at every level, with responses crucial from collective industries down to corporate management teams. Water dependency represents both company- and sector-specific operational and financial risks, including measures such as the water intensity of production[1]. Finally, water security includes physical, regulatory and reputational risks (Freyman et al., 2015; Hoekstra, 2014), as well as location-specific risks and impacts. Table 2 sets out how risks related to water security might manifest; Table 3 outlines how these risks can affect companies (directly) and investors (indirectly).

Physical risks	Regulatory risks	Reputational risks
• Operations • Supply chains	• Higher water prices • Water rationing • Emission permits • Obligatory water-saving technology	• Public awareness • Media campaigns

Table 2: Water security risks. Source: Hoekstra (2014)

Financial statements	Strategic	Financial markets
• Interrupted operations • Revenue • Costs and margins • Asset risk • Increased liabilities	• Ability to grow • Loss of market access • Ability to create or tap into new markets • Intrinsic benefit of product or service • Ability to adapt • Reputation and brand • Social licence • Ability to retain staff	• Perceived risk and growth of company by market players • Cost of capital • Credit ratings • Ability to tap financial markets • Ability to participate in growing new markets (green bonds) • Ability to retain staff

Table 3: Physical, regulatory and reputational implications due to water risks. Source: Freyman et al. (2015)

Many sectors rely on water for production or other industrial processes, such as irrigation, processing of materials, cooling, washing and cleaning (Lambooy, 2011). Even amongst those sectors most affected by water scarcity, the level of response can vary significantly (Figure 2). In the food and agricultural industries, water scarcity is exacerbated by agricultural expansion and increasing use of irrigation, hampering production (Larson et al., 2012). This has implications further down the supply chain for clothing companies, as cotton prices are affected by drought and water shortages in major cotton-producing regions like India and Brazil (Marengo et al., 2016). Similarly, the forestry industry needs water both for its feedstocks plantations and for producing pulp and paper (Manzardo et al., 2014). Likewise, many beverage companies are facing impacted operations and restricted production expansion (Alkaya and Demirer, 2015).

[1] Water use per unit of production (Adriaens et al., 2014).

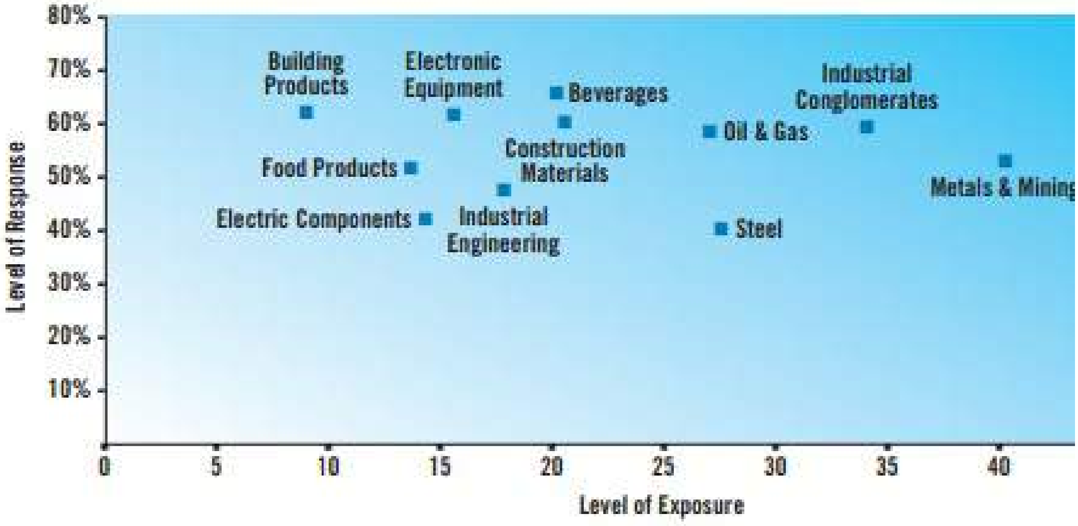

Figure 2: Level of exposure versus response by sectors. Source: Freyman et al. (2015)

Another sector impacted by water risk is the utilities sector, where power companies are facing the increased risk of de-rating events (where power production capacity is reduced), caused by water shortages and related risks, including high water temperatures and water contamination (Larson et al., 2012). Power utilities therefore face two problems: firstly, the frequency and severity of de-rating events are unknown; secondly, the associated costs are also unknown (Rice et al., 2012).

Competition for water is exacerbated by high-value industries such as energy production (de Fraiture et al., 2008). In a Global Electricity Initiative survey, 60% of energy industry leaders consider water availability as their number one challenge (GEI, 2014). The energy sector was responsible for around 15% of total freshwater withdrawals in 2010 (Flörke et al., 2013). Added to this, freshwater consumption required for global energy production is expected to increase due to increasing electricity demand in developing regions and thermal power generation relying on freshwater-cooling (Fricko et al. 2016); demand could more than double in the next 20 years (WEO, 2016). Hydropower and thermoelectric power generation technologies use significant amounts of water, and studies have shown those power plants are vulnerable to water scarcity (van Vliet et al., 2016; Liu et al., 2017a), with possible reductions in useable capacity of up to 74% (hydropower) or up to 86% (thermoelectric power) (van Vliet et al., 2016).

Water scarcity can still threaten those companies that do not operate in water-stressed areas, as around 22% of global water use is attributable to the production of export commodities (Hoekstra and Mekonnen, 2012). Countries that use significant amounts of water to produce export commodities, such as the USA, Brazil and Argentina, can be considered 'virtual water exporters'. Countries that rely on importing water-intensive commodities on the other hand, including most in Europe and North Africa, 'virtually import' water (Hoekstra, 2014). Figure 3 demonstrates which countries are importers (in red) and exporters (in green), as well as the relative quantity of 'virtual water' being traded.

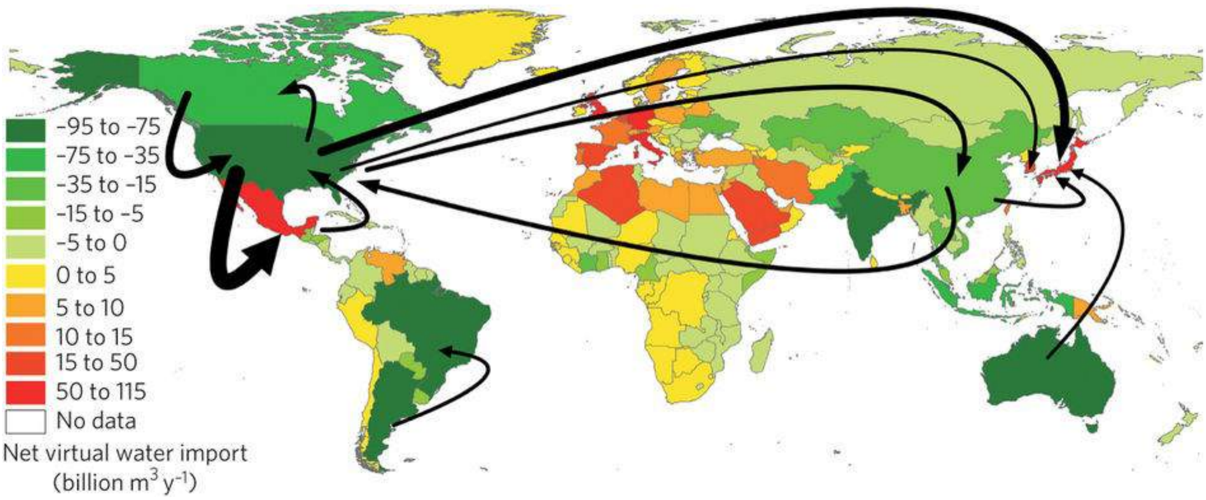

Figure 3: Virtual water balance per country and largest virtual water flows related to international trade. Source: Hoekstra (2014).

A further threat comes from those companies whose operations which are damaging in terms of both carbon emissions and water use. Oil sands require large amounts of water to separate oil from sand, and once burned for energy, emit significant levels of greenhouse gases (Kondash and Vengosh, 2015). Not only is this damaging to the environment, but any restrictions on water use or carbon emissions will result in restricted operations.

Despite the environmental impacts of corporate water use being more localised than the impacts of corporate carbon emissions, it is not easy to allocate regional environmental changes to the water usage of one company (Lambooy, 2011). This study focuses on the environmental risks and costs to companies, but the social impact of water use is also significant. This is covered in many papers (Lambooy, 2011; Flörke et al., 2013), and although not explored further in this study should remain an important consideration for investors.

2.3 Valuing Water Risk

2.3.1 Barriers to Valuing Water Risk

There are three main factors preventing investors from fully integrating water risks into their investment process. Firstly, water risks have less priority than other, more well-known risks, such as carbon emissions and stranded assets (Freyman et al., 2015). Secondly, water tariffs do not reflect the total cost of water (Ridley and Boland, 2015), and do not allow for any other measures of risk to be incorporated (such as baseline water stress). Finally, public disclosure of corporate water data is lacking (Lambooy, 2011; Linneman et al, 2015), which is partially driven by companies themselves failing to undertake rigorous monitoring of their water use.

The availability of high quality data is crucial for ESG analysis. Companies are increasingly reporting on ESG information voluntarily (Nilsson et al., 2008; Eccles and Saltzman, 2011), because of both mandatory reporting requirements (UNPRI, 2016) and voluntary efforts (UNPRI, 2017). Over 1000 companies voluntarily disclose water data to CDP (CDP, 2016). Whilst this should hypothetically aid investors make informed decisions, it should also give companies a strategic and competitive advantage (Hart, 2011). For example, by considering how to reduce energy usage and increase energy efficiency (as part of a more environmentally sustainable approach), companies should be better at managing energy price risk (Henriques and Sadorsky, 2010). Increased reporting, however, does not come without its flaws. For example, varying methodologies for measuring and reporting carbon emissions means that data may not be comparable across different company disclosures (Andrew and Cortese, 2011).

It is commonly held that water is undervalued (Freyman et al., 2015; Ridley and Boland, 2015), with water tariffs failing to reflect the real costs and benefits to all potential users. Although water prices have been seen to be artificially low in some places, subsidies are being phased out, leading to rising prices (Lambooy, 2011). Additionally, water tariff changes can occur abruptly, lagging behind the other financial costs. Other costs include increasing regulation, physical shortages, capital expenditure (*capex*) costs and the loss of social licence required to operate (Ridley and Boland, 2015). Capex might increase due to the increasing cost of securing water; this can be driven by changes in precipitation and urbanisation, as well as increased competition from other firms, from other sectors and from civil society (Ridley and Boland, 2015). An analysis conducted by the Natural Capital Declaration found 'no statistical correlation between urban water tariffs and water scarcity' (Ridley and Boland, 2015:p9). With market prices failing to internalise the full cost of water, and regulation frequently inadequate (Ridley and Boland (2015), overuse and mistreatment of the global water supply is inevitable, and, when subjected to obscure and ancient water property rights, it is unsurprising that there is little to no incentive for conservation in many regions (Eskaf, 2014).

2.3.2 Tools for Valuing Water Risk

There are a number of tools and frameworks that have been created to enable companies and stakeholders to better understand water valuation. Both WWF and WBCSD have created water valuation frameworks, although these are purposefully general in an attempt to be all-encompassing. More specialised water valuation tools exist, designed to target diverse sectors ranging from environmental economics to pure finance. The tools tend to focus on one aspect of water only, such as water risk, water assessment or water stewardship. Some of the tools that are more financially focused can be seen in Figure 4, which places each tool on a bilateral spectrum, depending on the tool's focus on financial certainty and value to the firm or to the environment. There are few tools that explicitly focus on water valuation, and those that do require intensive data input from the user, and are designed for companies rather than investors.

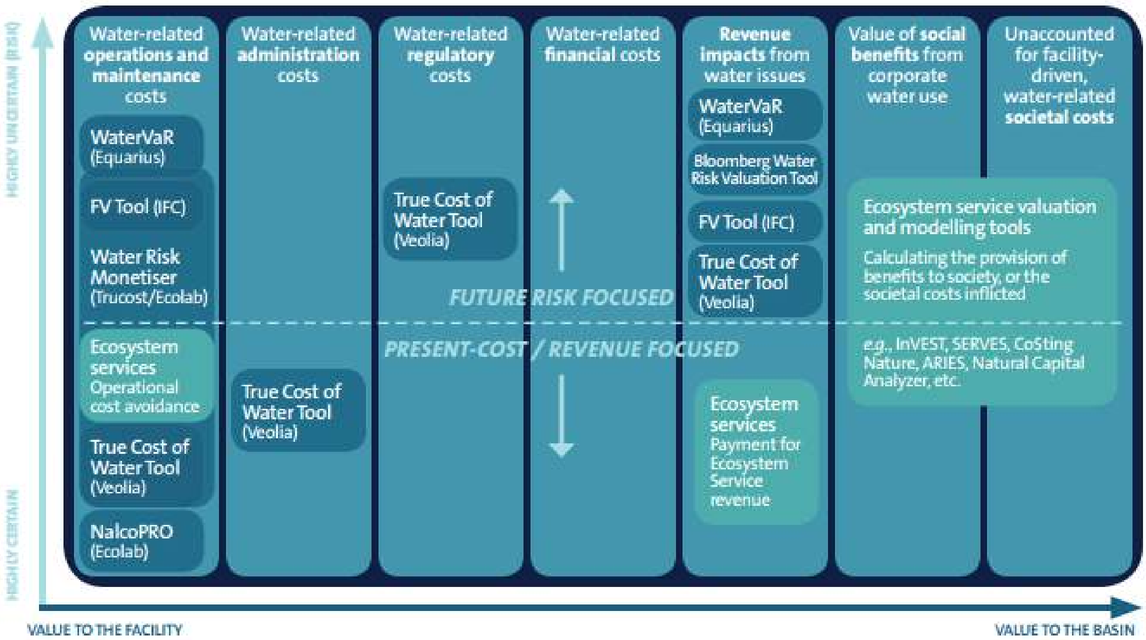

Figure 4: Examples of water tools in the context of financial valuation. Source: Morgan and Orr (2015)

The Total Economic Value (TEV) framework presents a theoretical and economics-based approach to water valuation, and can be used to convert non-monetary values into monetary forms (Pascual et al., 2010). The values it covers are shown in Table 4. Ridley and Boland (2015) use the TEV framework to propose a 'shadow price' of water. In order to analyse the economic value of an environmental indicator or asset, all costs and benefits to society should be expressed in monetary terms (Ridley and Boland, 2015). By applying this framework to water use, it is possible to calculate the economic value of water.

The approach taken by Ridley and Boland (2015) estimates the economic value of water across four uses (agriculture, domestic supply, human health and environmental services/biodiversity), and account for local variations in water stress and population. This approach however, only accounts for the 'use values' of water, and not the 'non-use values', and therefore may potentially underestimate the full value (TEV) of water. Because of this, the value of water that is calculated is referred to instead as the 'shadow price' of water. An important point to note is that shadow pricing actually has many definitions, with a common use being in water economics using residual valuation methods (Ziolkowska, 2015). In this study however, the shadow price can be interpreted as the 'opportunity cost' of water, ie the total value of all alternative uses of water, were it not withdrawn by the user in question.

Value type	Value sub-type	Meaning
Use values	Direct use value	Results from direct human use of biodiversity (consumptive or non-consumptive)
	Indirect use value	Derived from the regulation services provided by species and ecosystems
	Option value	Relates to the importance that people give to future availability of ecosystem services for personal benefit (option value in a strict sense)
Non-use values	Bequest value	Value attached by individuals to the fact that future generations will also have access to the benefits from species and ecosystems (intergenerational equity concerns)
	Altruist value	Value attached by individuals to the fact that other people of the present generation have access to the benefits provided by the species and ecosystems (intergenerational equity concerns)
	Existence value	Value related to the satisfaction that individuals derive from the mere knowledge that species and ecosystems continue to exist

Table 4: Total economic value framework. Source: Pascual et al. (2010)

One of the first financial models that integrated shadow pricing (and therefore water stress) was designed by the Natural Capital Declaration (Ridley and Boland, 2015), in partnership with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, the German Association for Environmental Management and Sustainability in Financial Institutions, as well as seven financial institutions from around the world. The tool uses geospatial water stress information from WRI, as well as site-specific corporate production and water use data, to quantify corporate water risk. The tool was designed specifically for corporate bond credit risk analysis, and enables users to assess the potential impact of water stress on a given company's credit ratios. This methodology has been extended by Park et al. (2015) to create the Water Risk Valuation Tool, which incorporates water shadow prices into a discounted cashflow model to analyse the water risk in equity valuations.

2.4 Integrating Environmental Factors into the Investment Strategy

2.4.1 ESG Integration

Environmental considerations such as water withdrawal and carbon emissions are often taken into account in the ESG factors used by investors to understand the non-financial dimensions of a company (van Duuren et al., 2016). ESG information can be used to create an ESG *score*, can be integrated into financial models, to identify opportunities and generally as softer information for investment managers (Freyman et al., 2015). Once this information has been analysed, it can be incorporated into an investment strategy. Table 5 shows the main strategies used by investors to use ESG information (Nielsen and Noergaard, 2011; Scholtens, 2014; Freyman et al., 2015; PRI, 2016).

Approach	**Method**	**Definition**
Fundamental (or traditional)	Adjusting company valuation models	Incorporating financial (single-decision modelling) or both financial and non-financial (dual-decision modelling) information into a valuation model
Quantitative (or systematic)	ESG factors	Using ESG performance to score companies
Smart beta Passive	Negative screening	Excluding particular firms or industries
Smart beta Passive	Positive screening	Concentrating on particular industries
Smart beta Passive	Best-in-class investing	Selecting the best 33% or 25% performers
Governance proxy Strategic and opportunity analysis	Activism	Filing petitions and voting on annual general meetings of shareholders
Governance proxy Strategic and opportunity analysis	Engagement	Meeting with the board of the corporate and trying to convince them to perform better on ESG

Table 5: Common ESG integration strategies. Source: various

The most common approach to incorporating ESG information into investment strategies is to negatively screen portfolios (Freyman et al., 2015; Amel-Zadeh and Serafeim, 2017). However, excluding or altering the weighting of certain stocks may result in a sector bias in the portfolio, for example with fewer manufacturing stocks held and more service sector stocks held (Einolf, 2007).

Underpinning these assessments are the indicators used to screen or weight companies, which have shown to be significant for valuing companies (Bassen and Kovacs, 2008; Rahdari and Rostamy, 2015), and can vary considerably depending on the research company producing them (Rahdari and Rostamy, 2015). However, despite the similarities and sometimes complementary aspects of indicators, there are certain ESG aspects that cannot be captured by indicators (Herva et al., 2011).

One set of metrics for analysing and comparing company water usage are known as *water intensity* metrics. These fractions using water withdrawal or consumption as the numerator (denominator), with a financial measure, such as revenue or units produced, as the denominator (numerator). Adriaens et al. (2014) extended the water intensity approach to estimate a financial measure of water risk, by combining the 'capital efficiency of water' metric with a traditional VaR measure. This compares a company's capital efficiency of water with the average portfolio capital efficiency of water to create a *waterBeta*; a company's *waterVaR* is then this waterBeta multiplied by a financial VaR measure.

2.4.2 ESG and Financial Performance

Many studies demonstrate a link between environmental performance and stock returns (Kruger , 2015; Hassel et al., 2005; Derwall et al., 2005; Halme and Niskanen, 2001; Konar and Cohen, 2001). Some find a positive relationship using Tobin's q ratio (Wahba, 2008), or a negative relationship with cost of capital (Dhaliwal et al., 2011; El Ghoul et al., 2011; Borghesi et al., 2014; Crifo et al., 2015). However, other studies suggest contradictory results (Horvathova, 2010; Nilsson et al., 2008), with one meta-study finding evidence of both positive and negative relationships, as well as either no significant relationship or a curvilinear relationship (Wahba, 2008). One limitation in that analysis is that there is little indication of how investors use environmental information (Jacobs et al., 2010; Dixon-Fowler et al., 2013). A further complexity is that correlation of environmental and market performance can be shown to be related to size and country location of the firm (Dixon-Fowler et al., 2013), as well as whether it is located in a well-developed financial market (Jo et al., 2015). This means that not only could returns be higher, but risk could also be lower for firms with a higher environmental performance (Ashwin Kumar et al., 2016; Manescu, 2011). The short-term timespan of many of these studies has been highlighted as a critical limitation of performance analysis (Revelli and Viviani, 2015; Cummings, 2000), with some studies recommending looking beyond performance analysis to understand the value of responsible investing (Barnett and Saloman, 2006; Gregory and Whittaker, 2013).

There are a number of dimensions to consider when understanding the environmental component of ESG. Many studies investigate ESG indicators as a whole (Friede et al., 2015), making it harder to determine the individual environmental effects. However, research that has analysed the individual components of ESG ratings shows that there is a link between these sustainability indicators and financial performance (Clarkson et al., 2011; Gompers et al., 2003). Nonetheless, a lack of sufficiently detailed knowledge on the financial impact of climate change has impeded attempts to model the risk it poses to investors (Dietz et al., 2016), and carbon emissions are often used as a proxy indicator for environmental performance (Lewandowski, 2015). Busch and Hoffmann (2007) showed that not only does the dependency on carbon-based materials and energy sources constrain competitiveness, but also that companies with high carbon emissions are likely exposed to fossil fuel price volatility as well. Increasingly restrictions in regulatory environments can also pose a significant a significant financial risk to companies (Griffin et al., 2017). Although these financial risks have yet to been reflected in company financial statements (Delmas and Nairn-Birch, 2011), the future impact of high carbon emissions are already priced in by the market (Delmas and Nairn-Birch, 2011; Lewandowski, 2015).

2.4.3 Water and Carbon Risk Integration

Water has been identified as an ESG risk (Bailey et al., 2016; MSCI, 2017; Freyman et al., 2015). There are still a number of barriers to incorporating water risk into investment processes however, including carbon superseding water as a priority for asset owners, lack of corporate performance data, and no effective risk framework (Freyman et al., 2015).

In terms of data, many sustainability and ESG research providers conduct research on water risk, although their outputs vary and neither data nor methodology are typically made publicly available. CDP collects self-disclosed data from companies, and produces its own analysis based upon this, although not all the companies it engages with provide data, with less than half responding to its questionnaire (CDP, 2016). MSCI collects its own data, producing analysis such as the water intensity of companies in the S&P500 (MSCI, 2017).

2.5 Research Objective

The literature reviewed establishes three points. Firstly, there is a relationship between water and climate change, and this poses a significant risk to companies. Secondly, few strategies are focused on reducing a portfolio’s exposure to a physical risk or factor, with most ESG-focused strategies instead integrating environmental information into an ESG ‘score’, which can then be used in a variety of ways to change a portfolio. Where strategies do focus on reducing a portfolio's physical risk, the majority of them focus on reducing a portfolio's exposure to carbon emissions. Finally, although water-related risks are widely accepted as a material risk to companies and an important indicator in ESG analysis, there have been few attempts to value water risk, and existing attempts have yet to be widely integrated into investment strategies, ESG-focused or otherwise.

The research objective of this study is therefore twofold: firstly, to develop a practically applicable framework for measuring water risk and incorporating it into portfolio analysis; secondly, to analyse whether reducing the carbon emissions in a portfolio also reduce this water risk.

3 Methodology

3.1 Chosen Methodology

The model aims to improve most ESG integration methods by assigning a financial value to water risk. To do this the *shadow price* of water will be applied to a company's water withdrawal, to determine the economic value of the water used by a company. Two different strategies will then be applied to a portfolio, the first with the aim of minimising the portfolio's exposure to carbon emissions, and the second with the aim of minimising the portfolio's exposure to water risk. These two portfolios will then be compared to assess the impact of reducing carbon emissions on a portfolio's exposure to water risk, and also to assess the impact of reducing a portfolio's water risk on its exposure to carbon emissions.

3.1.1 Valuing Water Risk

Ridley and Boland (2015) calculate the shadow price of water for a specific location using the following dependent variables: agricultural values, domestic supply values, human health impacts and environmental impacts. The independent variables, which are provided by WRI and Socioeconomic Data and Applications Center (SEDAC), are water stress and population. Both the dependent and independent variables can be seen in Figure 5.

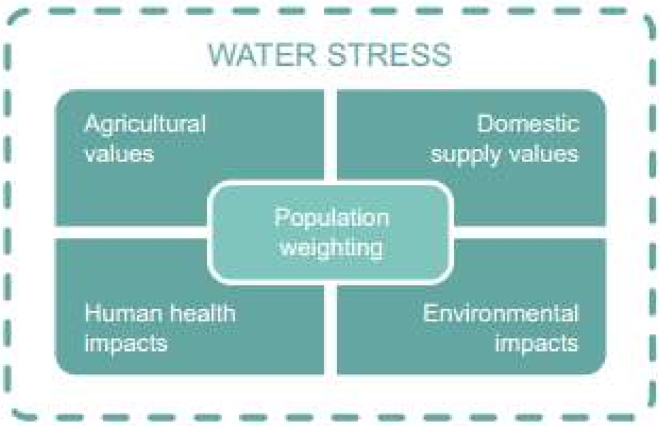

Figure 5 Shadow price of water calculation. Source: Ridley and Boland (2015)

Equation 1 shows the calculation for the shadow price of water for a given region (Ridley and Boland, 2015):

TEV = agricultural value + domestic supply price + human health + environmental impact

$$TEV = (0.4*W) + (P*0.8*(W+1)) + (P*D*(2*10^{-8}*W^2 + 10^{-8}*W + 10^{-7})) + P*W*0.1*(0.031*W^2 + 0.015*W)$$

Equation 1

Where:

W = BWS score
P = Population weight
D = Value of disability adjusted life year (DALY)

To calculate the agricultural value, existing estimates of the value of agricultural water use, between 2010 and 2015, are used to infer values for use at new locations (Ridley and Boland, 2015). The domestic supply price is based on the range of prices in the Global Water Intelligence 2014 tariff survey, and assumes that value increases with water scarcity. The human health and environmental impact variables used life-cycle analysis impact factors developed by Pfister et al. (2009), including a value for DALY. For the purposes of this study these variables will not be altered. The population weighting is intended to demonstrate the possible correlation between the value of water and population density.

Baseline water stress data, and therefore water shadow prices, are available for the years 2010, 2020, 2030 and 2040. Country-level water shadow prices for 2016 are be estimated by linearly interpolating between shadow prices in 2010 and 2020.

$$Shadow\ price_{year\ x} = ((shadow\ price_{year\ z} - shadow\ price_{year\ y})/shadowprice_{year\ y}) + shadowprice_{year\ y}$$

Equation 2

Where $y < x < z$

A company's average shadow price will be calculated by taking the production-weighted average shadow price from every country that company operates in. Company sales data will be used as a proxy for production distribution, as production data is rarely reported by companies.

$$Shadow\ price_{Company\ x} = \sum_i revenue_{xi} * shadow\ price_{Country\ i}$$

Equation 3

3.1.2 Integrating Water Risk into a Portfolio

One of the most common uses of ESG data is using information to negatively screen and/or underweight those companies that perform poorly in certain metrics. One example of this is the MSCI Low Carbon Index, which is based on the MSCI ACWI Index, and uses two metrics: carbon emissions relative to sales, and potential carbon emissions per financial currency unit of market capitalisation (MSCI, 2014). The Low Carbon Index is re-weighted to minimise these metrics, subject to four parameters: (1) tracking error[2] to the ACWI Index is less than 0.30%; (2) a

[2] The difference in performance between a portfolio and its benchmark.

company weighting in the Low Carbon Index cannot be larger than 20 times its original weighting; (3) the country weightings in the Low Carbon Index will not deviate by more than 2% from the original weightings; (4) the sector weightings in the Low Carbon Index will not deviate by more than 2% from the original weightings, with the exception of the Energy sector, on which there is no such restriction.

This methodology has been adapted for the purpose of the analysis. Only one metric will be measured: carbon emissions per GBP of market capitalisation. Two conditions will not be included: the tracking error of the portfolios will not be measured, and the country weightings are not applicable as all companies are listed in the UK. The company and sector weightings restrictions will be applied. For the purposes of the analysis, there is an additional constraint: a maximum underweight to an individual company of 25%. In a large portfolio, it is likely there would be no limit on the maximum underweight to an individual company, so it would be possible for some companies to be excluded. In a smaller representative portfolio, however, this additional restriction has been put in place, in order to best understand the impact of the underweight on the portfolio.

The total water risk cost to a company is estimated by multiplying a company's average shadow price for 2016 by its water withdrawal in that year (Equation 4). The two factors, carbon emissions and water risk cost, will be normalised for size by dividing by the market capitalisation of the company (Equations 5 and 6). The normalised factors can be considered as that company's contribution to the total exposure of the portfolio. The overall exposure of a portfolio to carbon emissions or water risk is then the sum total of each company's contribution to that factor (Equations 7 and 8), which be calculated in two different ways.

$$\textit{Water risk cost}_{\textit{Company x}} = \textit{Shadow price}_{\textit{Company x}} * \textit{Water withdrawal}_{\textit{Company x}}$$

Equation 4

$$\textit{Contribution to carbon emissions}_{\textit{Company x}} = \textit{Carbon emissions}_{\textit{Company x}} * ((\textit{Market cap}_{\textit{Company x}}) / \textstyle\sum_i \textit{Market cap}_{\textit{Company i}})$$

Equation 5

$$\textit{Contribution to water risk}_{\textit{Company x}} = \textit{Water risk}_{\textit{Company x}} * ((\textit{Market cap}_{\textit{Company x}}) / \textstyle\sum_i \textit{Market cap}_{\textit{Company i}})$$

Equation 6

$$\textit{Portfolio carbon emissions} = \textstyle\sum_i \textit{Contribution to carbon emissions}_{\textit{Company i}}$$

$= (\sum_i \textit{Carbon emissions}_{Company\ i} * \textit{Market cap}_{Company\ i}) / \sum_i \textit{Market cap}_{Company\ i}$

Equation 7

$\textit{Portfolio water risk} = \sum_i \textit{Contribution to water risk}_{Company\ i}$

$= (\sum_i \textit{Water risk}_{Company\ i} * \textit{Market cap}_{Company\ i}) / \sum_i \textit{Market cap}_{Company\ i}$

Equation 8

All the analyses will be performed in Excel, whose optimisation tool Solver uses a GRG Non-Linear[3] approach to provide the portfolio weights.

3.2 Justification of Choices

Few comprehensive models exist for integrating water risk into an investment strategy. For the purposes of this analysis, some elements of the existing water valuation tools (Ridley and Boland, 2015; Park et al., 2015) and existing environmentally-focused indices (MSCI, 2014) were modified. The remainder of this section explores the modifications or exclusions in more detail.

3.2.1 Water Intensity Metrics

Water intensity metrics were deemed not to carry sufficient information for the purposes of the model. Water intensity metrics present a method of linking water withdrawal with financial information, mainly revenue. Adriaens et al. (2014) extended this approach with the concept of *waterBet*a, which compares a company's capital efficiency of water to the average capital efficiency of water of the portfolio, and of *waterVaR*, which adds a relative financial VaR measure to the water beta metric. Although these metrics may be useful for comparing companies within a portfolio with respect to water usage, there are at least two limitations. Firstly, the *waterBeta* calculation is dependent on the benchmark data set, so comparisons are only possible within that data set itself. Secondly, the calculation does not allow for the inclusion of water stress forecasts. Addressing these limitations will be a key factor in this study's methodology.

3.2.2 Discounted Cashflow Model

Of the approach developed by Ridley and Boland (2015), the use of water shadow pricing to value water risk has been adopted, whilst the incorporation of water costs into discounted cashflow modelling has not. This approach has not been adopted for two reasons. Firstly, the point of the analysis is not to determine the true value of a company, but to assess the impact of water risk on

[3] Generalized Reduced Gradient algorithm, a robust non-linear programming method.

a portfolio. A discounted cashflow model allows for inconsistencies between the value in the model, the consensus or analyst value and the company's market value. Secondly, the shadow price of water represents an upper bound towards which a company's total cost of water approaches over time (Figure 6), so is likely to be significantly higher than the total cost of water ever paid by a company. Including water shadow pricing in a financial model can therefore reveal contradictory results, such as a total cost of water risk being higher than a company's total market value. Treating the shadow price of water as an expected cost will also result in the double-counting of a company's water-related costs, some of which will already be included in a company's financial statements (such as operating expenditure).

Figure 6: Shadow price increases with water stress. Source: Ridley and Boland (2015)

3.2.3 Portfolio Construction and Weighting

Although there a number of ESG-focused indices, these use ESG information to score companies, and company weights are decided on this basis. The MSCI Low Carbon Indices on the other hand, use optimisation targets and constraints to minimise a portfolio's actual physical exposure, represented by carbon emissions and fossil fuel reserves (MSCI, 2014). It is from these indices that the methodology has been adapted.

There are three optimisation objectives and constraints from the MSCI Low Carbon Target Index methodology that have not been used. The first is the restriction of the maximum weight of a company in the new portfolio to 20 times its weight in the original portfolio; due to the number of companies in the FTSE100, it is unlikely this constraint will be relevant. The second is restriction on country weights, which is not applicable as all companies in the original portfolio are listed in the UK. The third is that the tracking error of the new portfolio must be limited to 30bps relative to the original portfolio. As performance is not being analysed as part of this study, this constraint is also not relevant to the analysis.

An additional constraint has been added for the purpose of the analysis, which restricts the weight of a company in the new portfolio to a minimum of 75% of its weight in the original portfolio. This is due to the portfolio consisting of only 100 companies. If the restriction was higher then this would be more of a reflection of an active equity selection strategy.

3.3 Limitations

Although the shadow price calculation methodology attempts to allow for a range of water uses, there are inevitably further uses that are not included in the calculation, for example industrial production and fisheries habitat flows. Furthermore, the volumetric value is an average across all uses, whether included in the calculation or not, so it will not only will the average value simplify the many uses and values of water, but it is also not a true average.

Spatial precision is another limitation of the model. Although WRI and SEDAC data are available at a more granular level, the dependent variables are averaged on a global level, and water consumption data is available on a country-level only. For example, if a company's production sources are located in a water-stressed company, but not within a water-stressed region, then its exposure to water stress may be over-estimated. Additionally, the value of water is site-specific, so the approximations used for the dependent variables will not account for variations in, inter alia, supply, demand and local demographics. The population variable is also non-linear and arbitrary, ignoring whether water users are upstream or downstream.

However, given that most companies do not disclose water use by location, even this will not truly reflect a company's water stress risk, although any level of accuracy beyond this may be spurious, particularly for a large portfolio of equities. Indeed, Ridley and Boland (2015) assessed those companies within the Beverages sector on a country-level only, precisely due to the large number of sites (such as production sites, bottling plants, distilleries and breweries).

3.4 Data

For the purpose of this essay, the analysis will be performed on the constituents of the FTSE100 (as at 31 December 2016), which represent the largest companies (by market capitalisation) listed on the London Stock Exchange. The FTSE100 represents over 80% of the UK equity market, and around 5% of the total global equity market (Liu et al, 2017b). Of the 100 companies included in the analysis, the majority have international operations, and together they represent a diverse range of sectors. The global, diverse nature of the analysed companies means that the analysis should be more representative of a typical equity portfolio.

3.4.1 Water Shadow Price

Water shadow prices for each country are provided by Natural Capital Declaration (Ridley and Boland, 2015), and were calculated using country-level baseline water stress data from WRI (Gassert et al., 2014); the shadow prices are calculated using baseline water stress levels from 2010, and using projected baseline water stress for the year 2020 and beyond. Future projections of water stress and total water withdrawal are based on 'business-as-usual' climate and socioeconomic pathways.

3.4.2 Water Withdrawals

Water withdrawal is not comprehensively measured or reported on by companies, and is hindered by a lack of consistency and standardisation (Bassen and Kobacs, 2008). Individual company water withdrawal data will therefore be taken from three different sources. The first two sources rely on publicly available data: either water withdrawal as reported on the Bloomberg database, or that which is disclosed by the company itself, typically in an annual sustainability or corporate responsibility report. For companies with no publicly available data, water withdrawal will be estimated using Exiobase 2.1 MRIO tables (Exiobase, 2017), which are commonly used to track water withdrawals (Hubacek and Sun, 2005; Lenzen, 2006; Blackhurst et al., 2010).

3.4.3 Carbon Emissions

It is a requirement of companies that are publicly listed in the UK to disclose carbon emissions in their annual reports (UK Parliament, 2013). Disclosures vary, but the minimum that is provided by companies is the sum of Scope 1 and Scope 2 emissions, in tCO2e (tonnes of carbon dioxide equivalent greenhouse gases) which are used in the analysis.

3.4.4 Financial Information

Financial data are sourced from Bloomberg. Company revenue information, including the geographic distribution of revenue, is sourced from the annual reports of all companies in the FTSE100.

4 Results

This chapter sets out the results of the analysis, and offers some discussion as to their usefulness and application. First, the results of the water risk valuation model are presented, alongside some analysis of portfolio carbon emissions. Then, two portfolios are compared: one that aims to minimise carbon emissions, and one that aims to minimise water risk. Finally, the implications and limitations are discussed, and some areas of further research are proposed.

4.1 Data

4.1.1 Water Stress Data

The baseline water stress levels for each country is a component of each country's water shadow price. The WRI provides baseline water stress levels for every location, based on catchment[4] area, shown in Figure 7. However, for the purposes of this analysis, baseline water stress data will be used on a country level, which is also provided by WRI and shown in Figure 8. The WRI classifies water stress in five categories: extremely high (total water abstractions withdraw more than 80% of total water available), high (water abstractions are between 40% and 80% of total water available), medium to high (between 20% and 40%), low to medium (between 10% and 20%) and low (less than 10%). Figure 9 shows the key for how each baseline water stress level is represented in Figures 7 and 8.

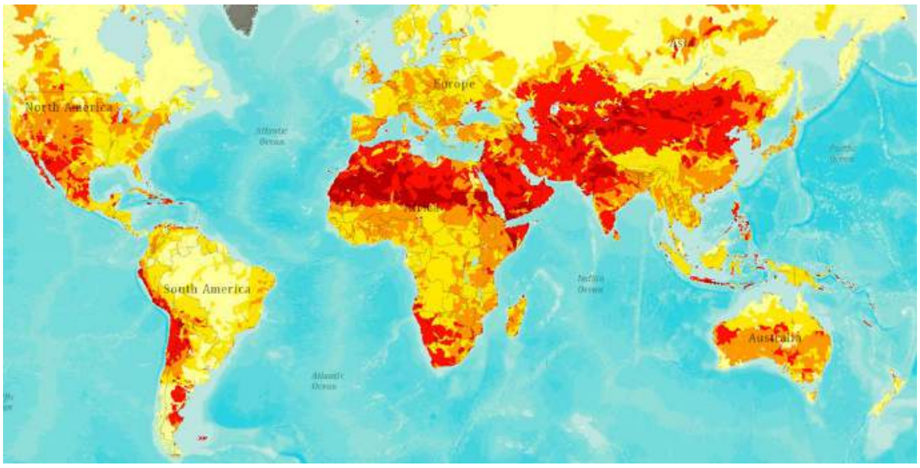

Figure 7: Baseline water stress by catchment. Source: WRI

[4] Areas of land that drain to a single outlet point (Gassert et al., 2014).

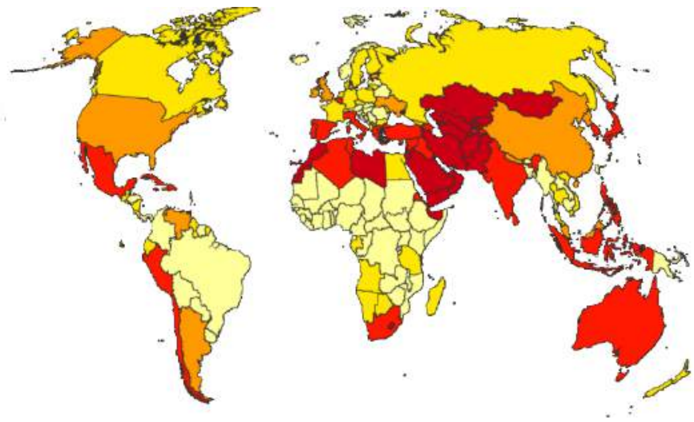

Figure 8: Baseline water stress by country. Source: WRI

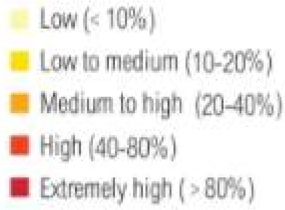

Figure 9: Ratio of withdrawals to supply. Source: WRI

4.1.2 Composition of the FTSE100

The analysis was performed on the constituents of the FTSE100, as a representative sample of companies in a portfolio. Each company can be classified into one of 11 sectors, the taxonomy of which is defined by the Global Industry Classification Standard (MSCI, 2016). Figure 10 shows the breakdown of the FTSE100 by sector, based on the market capitalisation of each sector as at the 31 December 2016. The biggest three sectors, Financials, Consumer Staples and Energy, make up more than half of the FTSE100 in terms of market capitalisation, but contain only 31 companies. The Consumer Discretionary sector, which makes up 9.4% of the FTSE100, contains the largest number of companies.

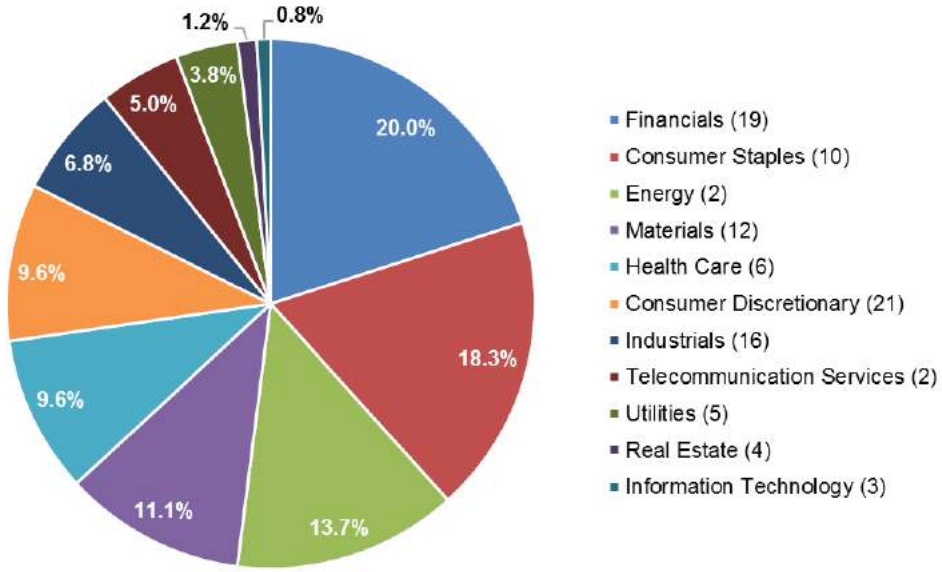

Figure 10: Breakdown of FTSE100 by sector.

Of the 100 companies that make up the FTSE100, the ten largest are shown in Table 6. These ten companies make up 44% of the total FTSE100 market capitalisation. This means that for any of these companies, a small change in the valuation or market capitalisation could have a large impact on the total market capitalisation of the FTSE100. Of the top ten companies, the two energy companies, BP and Shell, and mining company Rio Tinto, together account for 13.5% of the FTSE100.

Company	Sector	Market Capitalisation (GBP millions)	Index weighting
Royal Dutch Shell PLC	Energy	18,287,789	8.9%
HSBC Holdings PLC	Financials	13,263,854	6.5%
BP PLC	Energy	9,904,115	4.8%
Unilever PLC	Consumer staples	9,349,678	4.6%
British American Tobacco PLC	Consumer Staples	8,616,204	4.2%
GlaxoSmithKline PLC	Health Care	7,669,601	3.7%
Vodafone Group PLC	Telecommunication Services	5,874,756	2.9%
Diageo PLC	Consumer Staples	5,746,221	2.8%
Rio Tinto PLC	Materials	5,682,179	2.8%
AstraZeneca PLC	Health Care	5,614,456	2.7%

Table 6: Ten largest companies in the FTSE100

Figure 11 demonstrates the international exposure of the FTSE100 constituents, based on the geographic distribution of revenue as at 31 December 2016. Just under half of the total revenue comes from within the UK, with the next largest revenue source being the rest of Europe. This means that although the FTSE100 only contains companies with a UK listing, it is rather more indicative of a typical European investor’s exposure, allowing for a broader look at the global impact of carbon emissions and water risk.

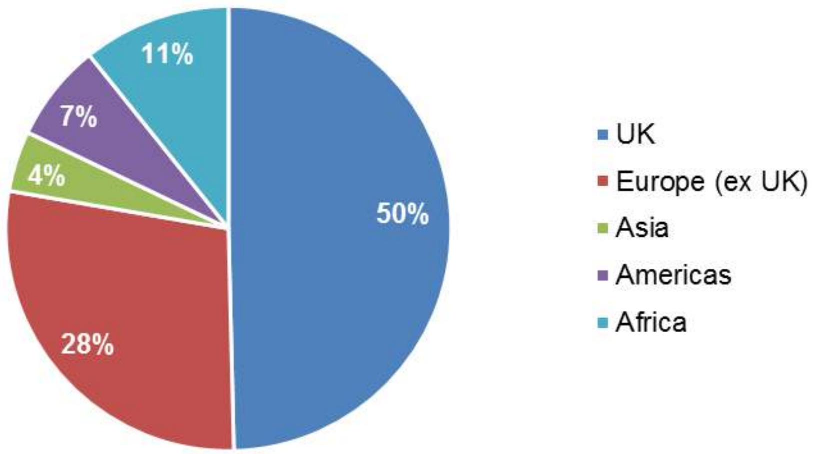

Figure 11: Geographic dispersion of revenue

4.2 Analysis

4.2.1 Overall Portfolio Analysis

A company's water risk is defined as its average shadow price multiplied by its water withdrawal rate. The total portfolio water risk is defined as the average water risk, weighted by each company's market capitalisation. Total portfolio carbon emissions are similarly defined, with each company's carbon emissions weighted by its market capitalisation. According to the analysis, the weighted average water risk cost of the FTSE100 represents around 1.3% of its total market capitalisation. The total emissions of the FTSE100 are 14,091,553 tCO2e.

This water risk cost represents not an expected cost that is likely to be experienced by the 100 companies over the next five years, but instead a theoretical maximum cost. Only in the event that the full cost of water withdrawal was internalised by every company in the FTSE100 that this cost would be realised, which is an unlikely scenario.

Two variables are used to calculate a company's water risk cost: the average baseline water stress score, which is used to calculate the shadow price, and the total water withdrawal. Figure 12 shows the exposure to, or distribution of, baseline water stress, both for the FTSE100 companies and on a global scale. The baseline water stress distribution of the FTSE100 is calculated by summing the revenue in each country, and using those weighted values to calculate how much revenue is derived from countries in each of the five categories of water stress. The baseline water stress distribution on a global level is calculated using weights based not on revenue but on gross domestic product (GDP).

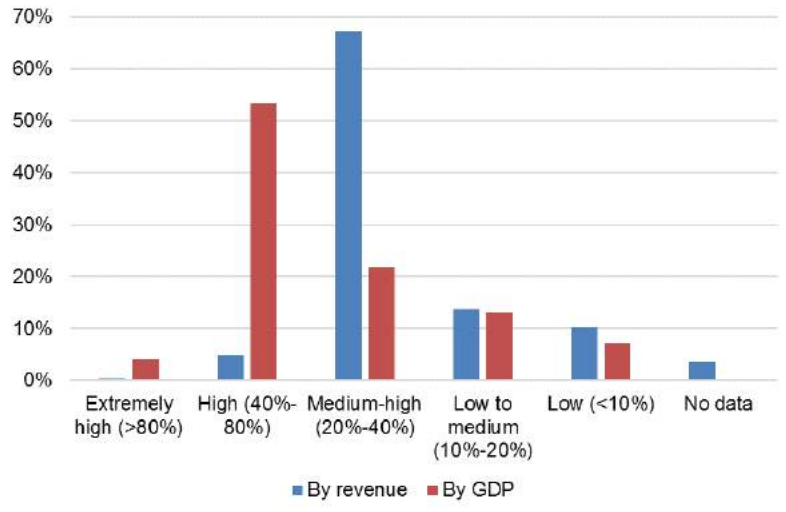

Figure 12: Distribution of baseline water stress in the FTSE100 and globally

In 2010, the companies in the FTSE100 were exposed to, in the majority, medium to high water stress (Figure 12). This means that around two thirds of the companies' operations were in countries where water abstractions account for between 20% and 40% of total water available. Most of the remaining exposure tends to occur in countries where water stress is less than 20%, with only a small percentage in countries of high water stress and no exposure to countries with extremely high water stress. Compared to the distribution of baseline water stress based on GDP, a greater proportion is exposed to extremely high and high levels of water stress, with less exposure to medium to high. These results are less surprising considering the majority of the FTSE100 revenue comes the UK and Europe. These regions that can be considered *virtual importers* of water risk, because they have high levels of imports produced in countries with higher levels of water stress (Hoekstra, 2014).

Figure 13 shows the expected change in water stress between 2010 and 2040. For each country, the percentage increase (or decrease) was weighted by either the total FTSE100 revenue for that country, or by its GDP, and then categorised by the degree of the increase. The results show that the average exposure of the FTSE100 companies is expected to remain around a similar level to that in 2010. This outcome is more in line with the GDP-weighted averages changes, as nearly 90% of countries (weighted by GDP) have a baseline water stress level that is expected to remain near the 2010 level in 2040.

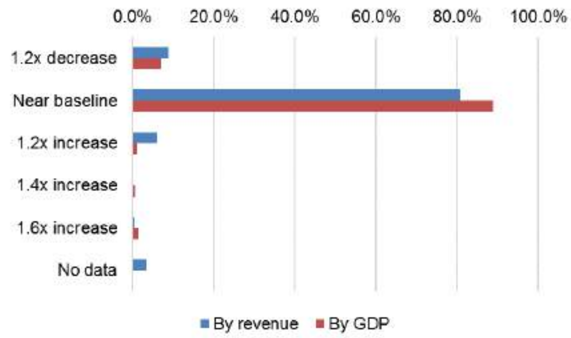

Figure 13: Change in baseline water stress from 2010 to 2040

4.2.2 Company Analysis

As mentioned above, a company's water risk is defined as its average shadow price multiplied by its water withdrawal rate. Figure 14 shows the 10 companies with the highest rates of annual water withdrawal, as well as the total water withdrawal of the remaining 90 FTSE100 constituents. Whilst mining company Glencore uses more water each than the remaining 90 FTSE100 companies combined, there are five other companies with a water withdrawal rate of more than 500,000ML[5], and 15 companies in total with a water withdrawal rate greater than 100,000ML.

Figure 14: Water withdrawal by company

The average water shadow price of a company is calculated by weighting every country's shadow price by the proportion of revenue earned by the company in that country. A company's geographic exposure can reveal an average shadow price, which enables water stress to be incorporated into a financial measure of risk. The ten highest average water shadow prices, in 2010 and projected for 2040, are shown in Table 7.

Alone, a company's shadow price can only be used as an indicator of that company's exposure to baseline water stress. Without taking a company's rate of water withdrawal into account, it is not possible to assess that company's total water risk. Of the companies listed in Table 7, a mining company like BHP Billiton is likely to have a far greater dependence on water withdrawal than a bank like Standard Chartered for example. A static shadow price cannot identify those companies that are faced with increasing water stress either. Rio Tinto's shadow price is only expected to rise by around 3% over 30 years, suggesting that although it is operating in many countries facing high water stress, it is not expected that Rio Tinto will face a significant increase in that water stress level.

Figure 15 shows those companies whose average shadow prices are expected to increase the most between 2010 and 2040. Whilst a company such as Anglo American, for example, has a lower shadow price than those companies shown in Table 7, but it is still expected to see this rise by 22% between 2010 and 2040 (Figure 15). However, analysing the expected change in shadow price in isolation may be misleading. The three companies facing the largest expected increase in shadow price are those with operations based solely in the UK, but the shadow price is still expected to remain lower than many other companies. Furthermore, the impact on the

[5] Mega-litres (equivalent to one million litres).

companies will probably be different for Barratt Developments and The British Land Company, two real estate companies, compared to Direct Line Insurance Group, an insurance company.

Company	**2010**	**Company**	**2040**
BAE Systems PLC	5.64	Fresnillo PLC	6.60
Fresnillo PLC	5.61	BAE Systems PLC	5.82
BHP Billiton PLC	5.12	Worldpay Group PLC	5.47
Standard Chartered PLC	5.11	Shire PLC	5.30
Worldpay Group PLC	5.08	BHP Billiton PLC	5.28
Rio Tinto PLC	5.00	Standard Chartered PLC	5.27
Shire PLC	4.95	Ashtead Group PLC	5.23
Paddy Power Betfair PLC	4.90	Pearson PLC	5.21
Pearson PLC	4.90	Rio Tinto PLC	5.17
Prudential PLC	4.88	Smith & Nephew PLC	5.13

Table 7: Highest average water shadow prices, 2010 and 2040 (US dollars)

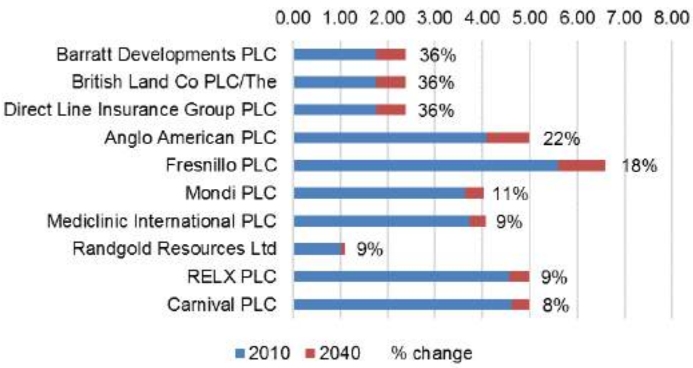

Figure 15: Expected change in average shadow price (US dollars), 2010-2040

On a company level, the shadow price of water alone does not carry sufficient informational power for investors to make any kind of decision. A company's average water price is calculated based on the average shadow prices of every country that company operates in. Although unlikely, it is possible a company may operate in nearly 200 countries, meaning any individual country operating under significant water stress would not have that significant an impact on the company's overall shadow price. Baseline water stress levels and projections are available on a localised level as well as on a country level, meaning that any company operations that take place in a location with a significantly different level of water stress from its own nation, would not be properly represented by that company's shadow price.

The link between carbon emissions and water usage is clear: Figure 16 shows the carbon emissions of the ten largest emitters in the FTSE100, as well as the total emissions of the remaining companies in the FTSE100, in MtCO2e. Of the ten largest emitters, half of these companies (DCC, Glencore, Rio Tinto, BP and BHP Billiton) are also the top ten largest users of water.

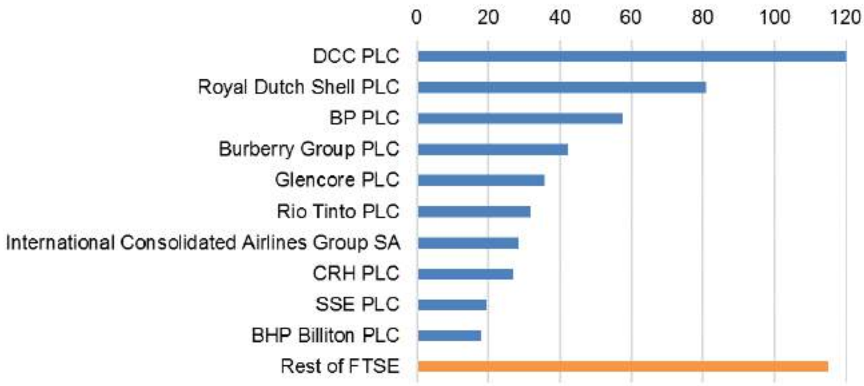

Figure 16: Carbon emissions by company

In addition, the links between water risk and water withdrawal are borne out by the data. Figure 17 shows those companies whose total water risk cost is greatest in relation to their market capitalisation. Most of the companies with the greatest water risk are also those companies with the largest water withdrawal. There are some outliers: Smurfit Kappa Group and G4S do not have particularly high rates of water withdrawal, but their comparatively small market values make their water risk more significant. Royal Dutch Shell, on the other hand, has a high rate of water withdrawal but a very high market capitalisation to absorb any water costs.

Similarly, Figure 18 shows the carbon emissions as a proportion of a company's market capitalisation, for the ten companies with the largest rates of carbon intensity. The absence of Royal Dutch Shell, BP, Rio Tinto and BHP Billiton reflects those companies' significant respective market values, in relation to their carbon emissions. Equally, the position of a company like EasyJet suggests its CO2e emissions are proportionately high compared to its market value. A company's water withdrawal is a significant factor the calculation of its total water risk cost. For example, Anglo American, which with its shadow price of US$4.09 is in the bottom 10% of the portfolio, still bears enormous potential total water risk costs, due to it being one of the largest water users at around 555,000ML. Conversely, publishing company Pearson has one of the highest shadow prices at US$4.90, but due to its very low levels of water withdrawal its total water risk cost is only £191,000. The market capitalisation weighting of a company also diminishes the impact of the shadow price. Standard Chartered is one of only six companies whose shadow price is greater than US$5.00, yet even with a shadow price of US$5.11, its total water risk cost is only around 0.1% of its total market capitalisation. On the other hand, Mondi is one of the few (nine) companies with a shadow price of less than US$4.00, but its significant water withdrawal means that its total water risk costs represents nearly 18% of its total market capitalisation.

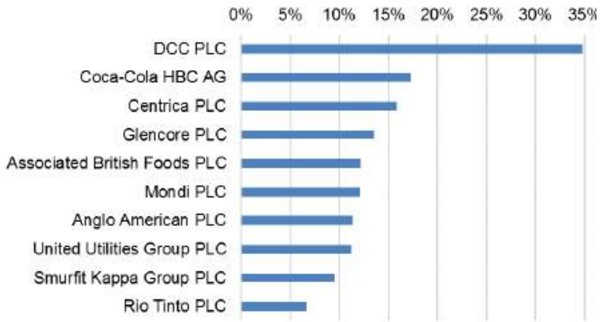

Figure 17: Individual company water risk

Figure 18: Carbon emissions per GBP market value

The relative size of a company's market capitalisation can have a meaningful impact on that company's contribution to the total FTSE100 water risk. A company's contribution is calculated by taking that company's percentage water risk, weighted by that company's market capitalisation, as a proportion of the total FTSE100 percentage water risk. Figure 19 shows which companies have the most significant contribution to the total water risk of the FTSE100. For example, although Glencore has a similar level of water risk as Centrica, the impact of its water risk is nearly three times as great as that of Centrica. Centrica's weighting in the FTSE100 is 0.6%, whereas Glencore's is 1.9%. Market capitalisation alone however does not completely dominate a company's contribution to overall water risk – of the ten largest companies in the FTSE100, only Rio Tinto and BP appear in Figure 19. On a portfolio level, a company's contribution to overall water risk is driven mainly by an individual company's water risk cost, with that company's weighting in the portfolio having less importance. For example, Coca-Cola represents just 0.3% of the FTSE100, but carries over 8% of its water risk. Equally, BAT is around 4.2% of the FTSE100 but its water risk contribution is negligible.

Similarly, a company's contribution to total portfolio emissions is calculated by taking the market-cap weighted carbon emissions of that company as a proportion of the total carbon emissions in the FTSE100. Just as for water risk, the addition of the market capitalisation weighting has an impact on a company's contribution, as illustrated in Figure 20, which shows the companies that have the greatest contribution to total portfolio emissions of the FTSE100. Carnival's total CO_2e emissions are just over 10m tCO_2e, which is significantly less than the level of carbon emissions from the ten largest emitters; however, it represents around 1.4% of the FTSE100 Index, meaning its contribution to total carbon emissions is significant. Conversely, Burberry has the fourth highest carbon emissions after DCC, BP and Shell, yet its contribution is much smaller, as it only represents around 0.3% of the FTSE100. The relatively small number of companies in the portfolio means that several companies can have a disproportionate impact. This is particularly the case for carbon emissions, as two of the largest emitters, energy companies BP and Shell, both also have comparatively large market values.

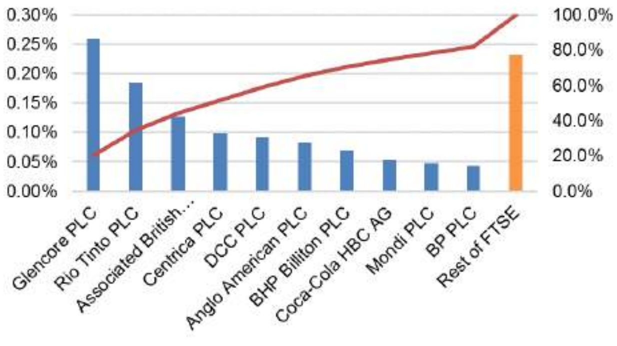

Figure 19: Company contribution to water risk

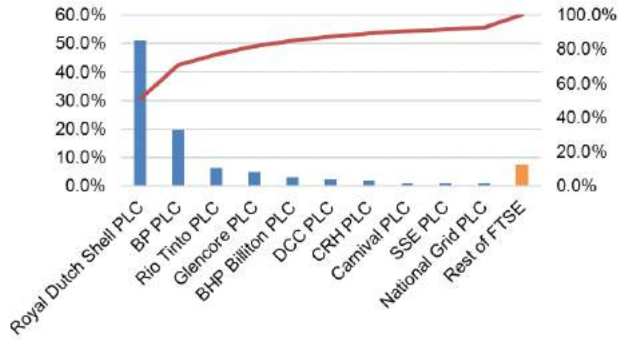

Figure 20: Company contribution to carbon emissions

4.2.3 Sector Analysis

Some sectors will be more exposed to water risk, and will have greater carbon emissions, than others. Figure 21 shows the average company water withdrawal by each FTSE100 sector. Four sectors in particular (Materials, Energy, Utilities and Consumer Staples) contain companies with large rates of water withdrawal. Figure 22 shows the average company CO2e emissions (in kilotons) for each sector. Aside from the Energy sector, which clearly has the highest average company emissions, the other sectors with higher than average emissions are similar to those with higher than average water withdrawal rates – particularly Materials, Industrials and Utilities.

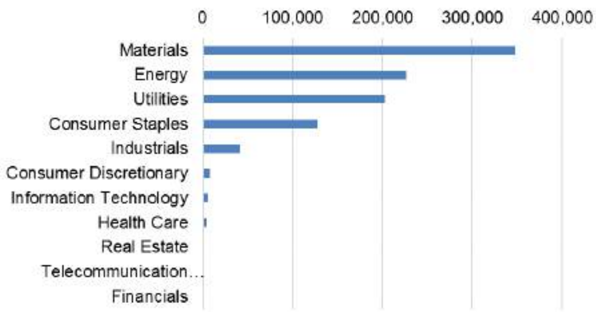

Figure 21: Water withdrawal by sector

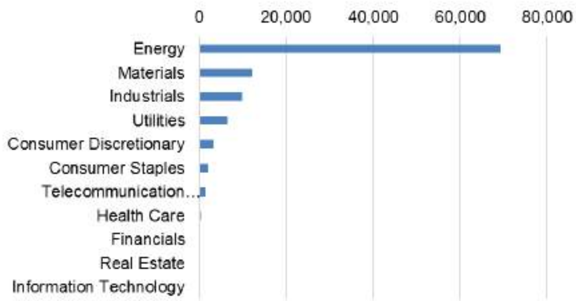

Figure 22: Average company emissions by sector

Sector-level water risk is calculated by summing the water risk cost for each company within a given sector, and taking that as a proportion of that sector's total market capitalisation. It can also be interpreted as the average water risk of each company in a given sector, weighted on a market capitalisation basis. This is shown in Figure 23, which shows that the five sectors with the largest water risk are also those with the largest average water withdrawal rates. The size of the sector's market capitalisation also has an impact here. For example, despite the Energy sector's water withdrawal being around 25 times greater than that of the Information Technology sector, the two sectors face a similar risk as a percentage of market capitalisation, at around 0.6%. This is a reflection of the large market capitalisation of the Energy sector, which represents around 14% of the FTSE100, compared to that of less than 1% for the Information Technology sector (Figure 10).

Figure 24 shows the average carbon emissions for a company in each sector. Energy has the highest average carbon emissions, although there are only two energy companies in the FTSE100, BP and Shell. Whilst the Materials sector contains some of the largest CO2e emitters in the FTSE100, such as DCC and Glencore, it consists of 12 companies in total, some of which have comparatively low carbon emissions.

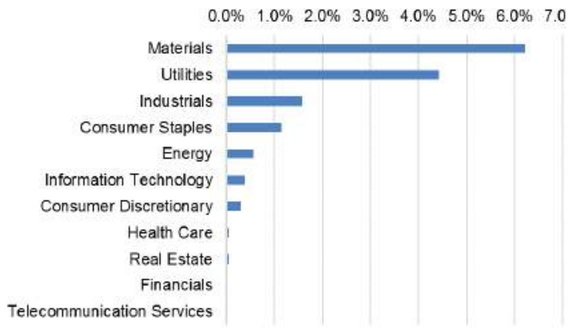

Figure 23: Average water risk by sector

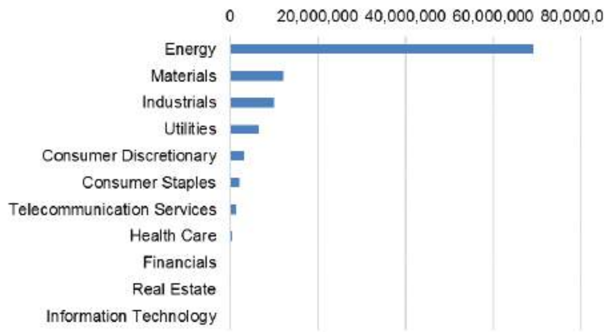

Figure 24: Average carbon emissions by sector

A sector's contribution to water risk is calculated by summing each contribution from the companies within that sector. Each sector's contribution to the total water risk in the FTSE100 is shown in Figure 25, which suggests that sector market capitalisation becomes less important in determining that sector's contribution to water risk, as despite the Energy sector's market capitalisation, its contribution to the total water risk of the FTSE100 is comparatively low. The Materials sector dominates, accounting for over half of the water risk within the FTSE100. Including the Consumer Staples and Industrials sectors brings this up to around 80%, and the Utilities sector up to around 90%. The Energy sector accounts for around 5% of the total water risk; the remaining sectors' contributions are negligible in comparison, with only the Consumer Discretionary sector accounting for more than 0.5% of the total risk.

A sector's contribution to portfolio carbon emissions is calculated by summing the (market capitalisation) weighted average carbon emissions of each company in that sector. Figure 26 shows each sector's contribution to total portfolio emissions, where the Energy sector accounts for more than two thirds of the FTSE100 emissions, with the Materials sector responsible for much of the rest.

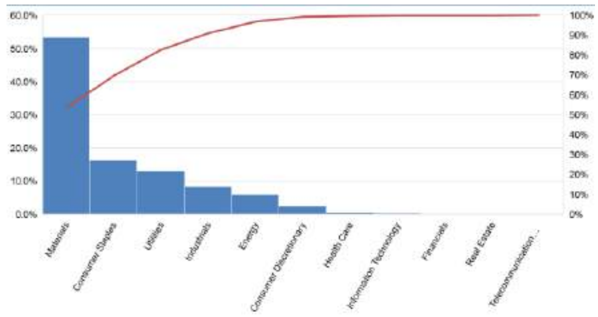

Figure 25: Sector contribution to total water risk

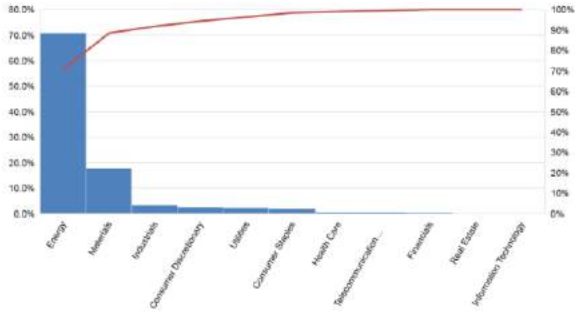

Figure 26: Sector contribution to total carbon emissions

Whilst some sectors contribute more to water risk and carbon emissions than others, even within those sectors they may be companies that make up the most of that contribution themselves. Figure 27 shows the same information as Figure 25, but only for the five sectors with the largest contributions to total water risk. Within these sectors, the contribution has been further set out to show the two companies within each sector that have the largest contribution to water risk, and the contribution of the remaining companies in that sector. The total number of companies in each sector is shown in brackets. Together these five sectors represent around 97% of the total water risk in the FTSE100. The Industrials and Utilities sectors' risk contributions are almost entirely made up of one company: DCC and Centrica respectively. Similarly Consumer Staples largely represents the risk contribution from two companies, Associated British Foods and Coca-Cola, whereas the only two companies in the Energy sector in the FTSE100 are BP and Shell. Only in the Materials sector do the remaining companies have a meaningful contribution, but even then half the risk in the sector comes from one company, Glencore.

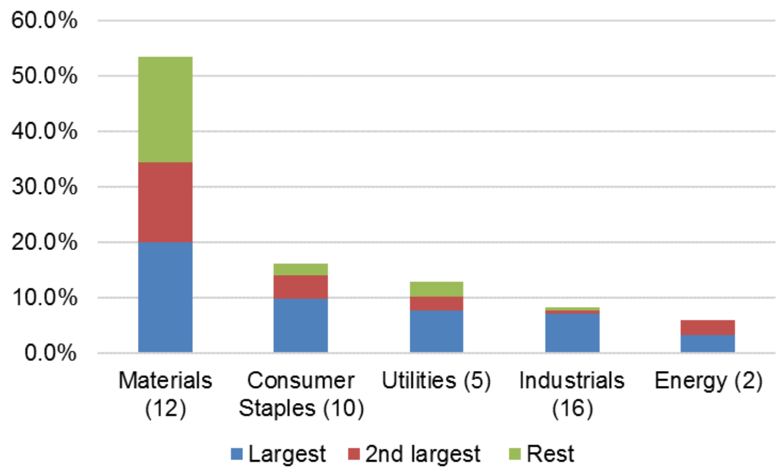

Figure 27: Contribution by sector and company

On a portfolio level, a company's contribution to overall water risk is driven mainly by an individual company's water risk cost, with that company's weighting in the portfolio having less importance. For example, Coca-Cola represents just 0.3% of the FTSE100, but carries over 8% of its water risk. Equally, BAT is around 4.2% of the FTSE100 but its water risk contribution is negligible.

4.3 Reducing the Water Risk and Carbon Emissions of a Portfolio

One of the most common uses of ESG data is using information to negatively screen and/or underweight those companies that perform poorly in certain metrics. In this section, two portfolios will be compared; one portfolio is constructed to minimise carbon emissions, whilst the other is constructed to minimise water risk. The portfolios are subject to two constraints: (1) the maximum underweight to an individual company of 25%; and (2) the sector weightings will not deviate by more than 2% from the original weightings, with the exception of the Energy sector, on which there is no such restriction

Table 8 shows two suggested portfolios – one with the company weights optimised so as to maximise the carbon emissions reduction, and the other with the company weights optimised so as to maximise the water risk cost. With a maximum company underweight of 25%, it is possible to achieve a 22.8% reduction in portfolio carbon emissions. The water risk in this portfolio, however, is only reduced by 10.4%. On the other hand, it is also possible to reduce the water risk by 23.5%, with the same maximum company underweight. Notably, there is not a significant difference in the carbon emissions reduction in both portfolios, with the reduction in emissions in the water-focused portfolio still around 21.9%, only slightly less than the carbon-focused portfolio.

Those companies that are underweighted in the portfolios are shown in Appendix I in Tables 9 and 10. Table 9 shows those companies that would be underweighted in a portfolio that was optimised to minimise carbon emissions. Table 10 shows those companies that would be underweighted in a portfolio that was optimised to minimise water risk exposure. Those companies that would be underweighted in both portfolios are shown in italics; of those companies, the only company subject to a different weighting is BHP Billiton, which is subject to a 22% underweight in the carbon-focused portfolio and a 25% underweight in the water-focused portfolio. Of the 12 companies that are underweighted in the carbon-focused portfolio, only three (Burberry, ICA and Standard Chartered) underweighted by 20% instead of the full 25% underweight. Similarly, of the 17 companies that are underweighted in the water-focused portfolio, BHP Billiton is the sole company not underweighted by the full 25%.

Sector	Original	Carbon weighted	Change	Water weighted	Change
Materials	11.1%	9.3%	-1.8%	9.1%	-2.0%
Utilities	3.8%	3.9%	0.1%	3.3%	-0.2%
Industrials	6.8%	7.2%	0.4%	6.5%	0.6%
Consumer Staples	18.3%	19.9%	1.6%	16.3%	0.7%
Energy	13.7%	10.3%	-3.4%	10.3%	-3.4%
Information Technology	0.8%	0.9%	0.1%	0.8%	0.1%
Consumer Discretionary	9.6%	9.9%	0.3%	9.3%	0.8%
Real Estate	1.2%	1.3%	0.1%	1.2%	0.1%
Health Care	9.6%	10.5%	0.8%	9.1%	0.9%
Financials	20.0%	21.5%	1.5%	22%	2.0%
Telecommunication Services	5.0%	5.4%	0.4%	5.5%	0.5%
CO2e emissions	14,091,553	10,963,093	22.8%	11,012,474	21.9%
Water risk cost	1.3%	1.2%	10.4%	1.0%	23.5%

Table 8: Effects of reducing carbon and water risk

Those companies that are underweighted in the portfolios are shown in Appendix I in Tables 9 and 10. Table 9 shows those companies that would be underweighted in a portfolio that was optimised to minimise carbon emissions. Table 10 shows those companies that would be underweighted in a portfolio that was optimised to minimise water risk exposure. Those companies that would be underweighted in both portfolios are shown in italics; of those companies, the only company subject to a different weighting is BHP Billiton, which is subject to a 22% underweight in the carbon-focused portfolio and a 25% underweight in the water-focused portfolio. Of the 12 companies that are underweighted in the carbon-focused portfolio, only three (Burberry, ICA and Standard Chartered) underweighted by 20% instead of the full 25% underweight. Similarly, of the 17 companies that are underweighted in the water-focused portfolio, BHP Billiton is the sole company not underweighted by the full 25%.

The 12 companies that are underweighted in the carbon-focused portfolio are the ten largest emitters in the FTSE100, plus Carnival and Standard Chartered. Despite G4S having significant carbon emissions in relation to its market capitalisation, its low carbon emissions overall mean that it is not subject to underweighting. The 17 companies that are underweight in the water risk-focused portfolio are the also those 17 companies with the highest rates of water withdrawal, with the exception of CRH and the inclusion of Imperial Brands, the next highest user of water.

4.4 Implications of the Results

4.4.1 Valuing Water Risk

There is limited research into water risk valuation, so this model presents an alternative water risk valuation model methodology to Adriaens et al. (2014), as it incorporates baseline water stress and a TEV framework alongside the simple water withdrawal data. Whilst tariffs have been shown to vastly undervalue water (Freyman et al., 2015), using a TEV framework to develop the shadow price can potentially give a much better indication of the cost to society, the environment and other material factors that may or may not, eventually, represent a cost to the user. The TEV framework also enables water stress to be expressed in monetary terms, which is more relevant to financial analysis than the sole use of physical data (such as water withdrawal or baseline water stress).

The approach was adapted from that proposed by Ridley and Boland (2015) and Park et al. (2015), but simplified for the purposes of applying the methodology to a large portfolio of companies. The incorporation of water shadow pricing into a discounted cashflow model implies that it is a cost that will be borne by the company. This study instead considers water risk as a potential cost, in relation to a company's market capitalisation, thus providing a comparable normalised metric that is grounded in financial analysis. This also supports the existing research that suggests that ESG information is not reflected in valuation models but is priced in by the market (Delmas and Nairn-Birch, 2011; Lewandowski, 2015).

Around a third of the FTSE100 (by revenue) was not exposed to higher than average levels of water stress (Figure 12). Although not unexpected, this exposes a limitation of the method proposed by Ridley and Boland (2015) and Park et al. (2015), that of applying water shadow prices to an entire company's water withdrawal. In doing so, it is assumed that all of a company's operations, in every location, will have an additional cost to bear, even if those operations are not in a water stressed area. The model does not allow for the probability of a company bearing the full shadow price of water, or at least to what extent.

In focusing on the FTSE100 constituents, this is the first study to conduct practical analysis on a representative portfolio of companies; this complements prior research that has previously only focused on valuing the water risk of a limited number of sectors (Ridley and Boland, 2015; Park et al., 2015; Adriaens et al., 2014). The analysis reinforces the recommendation for the introduction of water shadow pricing to estimate water risk exposure. This represents an improvement on current ESG practices of only using water withdrawal to identify those companies most at risk. Although this study examined a comparatively small set of companies listed in one country, the results should be generalisable to other larger portfolios.

4.4.2 Reducing Water Risk and Carbon Emissions

This approach integrates the water risk valuation methodology proposed by Ridley and Boland (2015), with the rules developed for the MSCI Low Carbon Index (MSCI, 2014). The findings contribute to the evaluation of the relationship between two important environmental ESG factors, carbon and water. An implication of this is that understanding the relationships between ESG factors can improve ESG performance.

The results are of direct practical relevance to investors, suggesting that investment strategies can be extended from satisfying one to satisfying multiple environmental objectives. Investors can also better understand the direct risk exposure in their portfolios, rather than relying on the compartmentalisation of ESG data into an abstract scoring system.

The findings suggest that this approach would be particularly beneficial for portfolios where carbon emissions are already measured or minimised. In the FTSE100, BP and Shell were responsible for most of the portfolio carbon emissions, and therefore any underweight to those companies resulted in a significant corresponding reduction in carbon emissions. After these two companies, however, underweighting companies with high contributions to carbon emissions saw diminishing returns. It is the selection of which of the remaining companies to underweight that makes a significant difference to water risk. SSE for example, has a similar contribution to portfolio carbon emissions as National Grid, but its contribution to portfolio water risk is three times greater. Although choosing to underweight SSE over National Grid might result in a slightly smaller reduction in carbon emissions, it would greatly increase the reduction in water risk.

4.5 Limitations

4.5.1 Data Granularity

Although water stress levels, and consequently water shadow prices, are available on a very specific location basis, the model only uses water shadow prices on a country basis. These country-level shadow prices are based on the average water stress level for that country. This could be problematic for two reasons: firstly, the average water stress level does not give any indication of the range of water stress levels experienced in that country – water withdrawals in a country could all tend towards and average, or the dispersion could be high with areas of both very high and very low water stress. Secondly, using country-level shadow prices does not allow for the use of location-specific data for a given company. The model is therefore unable to allow for whether a company is operating in a specific region of high or low water stress. An example of this is Anglo American – using the Natural Capital Declaration model, the publicly available version of which contains location-specific production data, Anglo American's average shadow price is estimated to be USD1.41 (in 2010). On the other hand, using country-level data, Anglo American's average shadow price is estimated to be USD4.09 in 2010. So although Anglo American is operating in those countries with comparatively high levels of water stress, within those countries it is operating in regions with lower water stress levels. There are two factors, however, that make this less important. Firstly, it could be argued that this level of accuracy is spurious, given how significant a company's water withdrawal is in determining its exposure to water risk. Secondly, there is a paucity of publicly available location-specific company production data.

4.5.2 Omitted Water Risks

There are many factors that have been omitted from this model, that although unlikely to be material on a portfolio level, could be significantly more so a company level. Issues such as investment in local water storage, fluctuations in water availability and water efficiency expenditure can all affect the impact of water risks, as well as the timing. Other physical risks could in included, such as those by WRI: inter-annual variability, seasonal variability, flood occurrence, drought severity, upstream storage and groundwater stress. These risks are quantifiable, so they have the potential to be incorporated into a water risk model. However, each factor would need to be represented in financial terms, just as baseline water stress has been incorporated into shadow pricing methodology.

The WRI also provides data on non-quantifiable physical risks, as well as regulatory and reputational risks. Qualitative physical risks include measures of return flow ratio and upstream protected land; regulatory and reputational risks include media coverage, access to water and threatened amphibians. These risks all fall within the 'water security' element defined by Freyman et al. (2015). Other aspects include water dependency (identifying both sector-specific and company-specific operations with high water needs) and response (analysing both corporate management and industry responses to water risk). There are many more factors than those set out here, however given that none of these considerations are quantifiable, the inclusion of one would require a subjective assessment of its significance within the model.

4.5.3 Measures of Risk

The carbon and water data model inputs are static, with carbon emissions based on the emissions in one year (2016), and water withdrawal assumed to be increasing at constant rate, also from a baseline water withdrawal level in 2016. The model therefore does not allow for any measures of improvements in efficiency to be included, which could have a significant impact on the results. In terms of carbon emissions, many companies in fact report falling emissions year-on-year. In terms of water withdrawal, some companies (particularly those more exposed to water risk) are investing in resources and management plans to improve their water efficiency. Although it is slightly more difficult to quantify a company's approach to water risk management, efficiency could be measured by weighting carbon emissions or water withdrawal by a company's revenue or production. If this were to be included in the model it would be likely this would be measured alongside the static measures, which would require users to specify which metric (efficiency and total exposure) was a priority and by how much.

Indirect exposure, to both carbon emissions and water withdrawals, has not been allowed for in the model. In terms of carbon emissions, not all companies report on Scope 3 emissions, and those that do are likely to follow different reporting methodologies. Likewise, water risk in a company's supply chain can be significant (Hoekstra, 2014) but are generally difficult to measure. Double-counting between companies, particularly for carbon emissions, could present a material issue were indirect risks to be incorporated into the model. It could also be argued that adding estimates of additional water costs in the supply chain could oversimplify the complexity of the pass-through costs.

4.6 Further Research

The model would benefit from improvements to the existing data. Obtaining more location-specific company data would enable the analysis to benefit from the granularity of the WRI baseline water stress data. Other physical risks could also be incorporated from WRI. Companies could be encouraged to publish water withdrawal data (where they don't already), or more detailed water withdrawal data, such as by location or product line.

There are a number of amendments to the model that could give users and investors a better understanding of the water risk faced by companies. The negative impact on revenues could be included, as in the model developed by Park et al. (2015). A percentage factor could be applied to the total water shadow price, to reflect the actual costs that could be borne by companies, or equally those costs that have already been internalised. Lower water costs could be accounted for either for different operations (for example for cooling water in the utilities sector) or for different industry technology costs around the world.

Finally the output of the model should be verified. The water shadow price methodology might benefit from further research if it is to be more widely used by investors. It is also important to investigate the impact of the portfolio constraints on returns, for example by testing the portfolio against the 30bps tracking error target of the MSCI Low Carbon Index (MSCI, 2014). The metrics of the MSCI Low Carbon Index itself could be incorporated, for example by analysing more specifically carbon emissions relative to sales and potential carbon emissions (using fossil fuel reserves as a proxy) per dollar of market capitalization. The model could also be run using a larger, more international portfolio, to compare the results with the FTSE100.

5 Conclusion

The aim of this study was to assess the impact of water shadow pricing on a portfolio, and to understand the interplay between reducing carbon and water risks. The analysis incorporated water shadow pricing methodology, as developed by Ridley and Boland (2015), to analyse the total cost of a company's water use. The framework was extended to evaluate and quantify water risk exposure, in order to analyse the total risk within a typical investment portfolio. In doing so, this enabled water risk to incorporate both the internal and external costs of water, as well as allowing for where companies operate in areas of water stress. The results suggested that if the full cost of a company's water withdrawal in 2016 was internalized, then this would represent around 1.3% of the total market capitalization of the FTSE100. The weighted average carbon emissions of the FTSE100 was around 14m tonnes in 2016. Two portfolios, based on the FTSE100, were constructed, with a maximum underweight (compared to the FTSE100) of 25%. The portfolio that reduced carbon emissions by 22.8%, also saw a modest reduction in water risk by around 10%. However, the portfolio that reduced water risk by around 23.5%, also saw a meaningful reduction in carbon emissions of over 21%. The contribution of this study is twofold. First, a portfolio water risk premium is identified, allowing different portfolio strategies to be compared with respect to water risk. Investors can make use of the portfolio water risk premium as a comparable indicator for the specific water risk within an investment portfolio. Secondly, the analysis proposes that investors could reduce both carbon emissions and water risk exposure with the same investment strategy.

There are three broad limitations to this analysis: data granularity, data stationarity and the measures of risk that are incorporated into the model. Although it is not expected that addressing these limitations would alter the results of the analysis materially, the model would still benefit from improvements in these areas. Data granularity is an issue that is unlikely to be solved by researchers or investors alone. The responsibility lies with companies to measure and disclose water-related information, such as production-specific water intensity rates and location-specific water withdrawal rates. Even financial information that is not related to water use may help improve the model. Data stationarity on the other hand is more easily addressed by users of the model. Measures of improving efficiency could be measured and incorporated. Water withdrawal and carbon emissions could be projected and discounted back, particularly given the WRI baseline water stress data are forecasted for the years 2020, 2030 and 2040. Finally, the WRI provides data on other measures of physical water risk, beyond baseline water stress. These may be adaptable to a similar methodology as water shadow pricing, although this is something that is well beyond the scope of this study.

As the key concept in valuing water risk is water shadow pricing, this would benefit from future research, both to verify the weightings and factors applied to baseline water stress, and to understand how it might relate to the actual cost of water risk internalised by companies. It would be particularly interesting to apply this methodology to a larger, more global portfolio than the FTSE100, to understand how the profile of the portfolio water risk might change, and also to see whether the relationship between water risk and carbon emissions is still identifiable. Finally, studies should examine the implications of minimising water risk on pure financial performance.

This study therefore provides a straightforward method for integrating water risk into an investment strategy, and also suggests that the two targets of reducing a portfolio's carbon emissions and water risk are neither difficult to measure nor mutually exclusive. At the very least, investors are advised to start measuring the water risk in their portfolios, where they do not already do so, and particularly for those portfolios where carbon emissions are monitored. Where carbon emissions are monitored, and where investment strategies are targeted at minimising portfolio carbon emissions, investors are encouraged to monitor water risk alongside carbon emissions.

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Appendix I

Company	Old weighting	Underweight	New weighting	Old CO2 emissions	New CO2 emissions	Old water risk	New water risk
BHP Billiton PLC	*2.4%*	*-25%*	*1.8%*	*439,199*	*329,400*	*0.09%*	*0.07%*
BP PLC	*4.8%*	*-25%*	*3.6%*	*2,773,939*	*2,080,454*	*0.04%*	*0.03%*
Burberry Group PLC	0.3%	-20%	0.2%	124,913	99,930	0.00%	0.00%
Carnival PLC	1.4%	-25%	1.1%	148,112	111,084	0.00%	0.00%
CRH PLC	1.1%	-25%	0.9%	307,912	230,934	0.02%	0.01%
DCC PLC	*0.3%*	*-25%*	*0.2%*	*317,676*	*238,257*	*0.13%*	*0.10%*
Glencore PLC	*1.9%*	*-25%*	*1.4%*	*683,085*	*512,314*	*0.41%*	*0.31%*
International Consolidated Airlines Group SA	0.5%	-20%	0.4%	128,244	102,595	0.00%	0.00%
Royal Dutch Shell PLC	*8.9%*	*-25%*	*6.7%*	*7,202,859*	*5,402,144*	*0.04%*	*0.03%*
Rio Tinto PLC	*2.8%*	*-25%*	*2.1%*	*884,145*	*663,109*	*0.14%*	*0.11%*
SSE PLC	*0.7%*	*-25%*	*0.5%*	*141,777*	*106,333*	*0.06%*	*0.04%*
Standard Chartered PLC	1.1%	-20%	0.8%	2,135	1,708	0.00%	0.00%
Rest of FTSE	73.8%		80.3%	937,557	995,248	0.77%	0.82%

Table 9: Underweighted companies in a carbon-focused portfolio

Company	Old weighting	Underweight	New weighting	Old CO2 emissions	New CO2 emissions	Old water risk	New water risk
Anglo American PLC	0.7%	-25%	0.5%	128,362	96,272	0.06%	0.05%
Associated British Foods PLC	1.0%	-25%	0.8%	90,783	68,087	0.15%	0.12%
BHP Billiton PLC	*2.4%*	*-22%*	*1.9%*	*439,199*	*341,227*	*0.09%*	*0.07%*
BP PLC	*4.8%*	*-25%*	*3.6%*	*2,773,939*	*2,080,454*	*0.04%*	*0.03%*
Coca-Cola HBC AG	0.3%	-25%	0.2%	8,210	6,158	0.13%	0.10%
Centrica PLC	0.6%	-25%	0.5%	31,934	23,950	0.12%	0.09%
DCC PLC	*0.3%*	*-25%*	*0.2%*	*317,676*	*238,257*	*0.13%*	*0.10%*
Glencore PLC	*1.9%*	*-25%*	*1.4%*	*683,085*	*512,314*	*0.41%*	*0.31%*
InterContinental Hotels Group PLC	0.4%	-25%	0.3%	20,002	15,001	0.02%	0.01%
Imperial Brands PLC	1.9%	-25%	1.4%	3,620	2,715	0.02%	0.01%
Mondi PLC	0.4%	-25%	0.3%	18,880	14,160	0.07%	0.05%
Royal Dutch Shell PLC	*8.9%*	*-25%*	*6.7%*	*7,202,859*	*5,402,144*	*0.04%*	*0.03%*
Rio Tinto PLC	*2.8%*	*-25%*	*2.1%*	*884,145*	*663,109*	*0.14%*	*0.11%*
Randgold Resources Ltd	0.3%	-25%	0.2%	2,350	1,762	0.01%	0.01%
Smurfit Kappa Group PLC	0.2%	-25%	0.2%	14,291	10,718	0.04%	0.03%
SSE PLC	*0.7%*	*-25%*	*0.5%*	*141,777*	*106,333*	*0.06%*	*0.04%*
United Utilities Group PLC	0.3%	-25%	0.2%	1,265	949	0.07%	0.05%
Rest of FTSE	72.1%		79.0%	1,329,176	1,480,296	0.10%	0.11%

Table 10: Underweighted companies in a water-focused portfolio