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The exposure of a fresh fruit and vegetable supply chain to global water-related risks

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ABSTRACT
We have combined estimates of the UK's supply of fresh fruit and vegetables (1996 – 2015) with estimates of water requirements and water scarcity in producing countries, to identify where the supply is exposed to physical, regulatory and reputational water risks and how this has changed over time. Some 76% of the freshwater consumed in the supply of fresh fruit and vegetables to the UK is withdrawn overseas. The supply chain is particularly exposed to water risks in Spain, Egypt, South Africa, Chile, Morocco, Israel and Peru. Exposure has increased over time.

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Introduction

The production of fresh fruit and vegetables (FF&V) requires large quantities of water. With population growth, dietary change and the greater recognition of the importance of fruit and vegetable consumption for health, demand is increasing, and the areas where FF&V are cultivated have been extending, particularly in semi-arid and arid environments where water shortages are common (Kumar, Rouphael, Cardarelli, & Colla, 2017).

Water is used in many stages of the FF&V value chain including growing (rainfall, irrigation), processing (washing produce, pack-house wash-down, sanitation) and distribution (wash-down). As such, a secure and reliable supply of water of an appropriate quality is critical to businesses that grow and process fruit and vegetables, and consequently to the security of supply to retailers and ultimately consumers.

FF&V value chains are exposed to different types of water risk. In this article we focus predominantly on the physical, regulatory and reputational risks.

Physical risks such as drought are related to physical access to water. Drought may mean that water is not available for irrigation of FF&V, leading to plant water stress that during critical growth periods (which vary by species) can adversely affect a plant's ability to take up nutrients, limiting growth, yield and affecting the quality of the resulting produce (Kumar et al., 2017). At the extreme, water stress may lead to the abortion of flowers and eventually plant death (Ripoll et al., 2014). This can have potentially severe economic consequences for stakeholders within the value chain.

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Supplementary data can be accessed here

Drought in California in 2015 was estimated to have caused 220,000 ha to be fallowed and led to total vegetable crop revenue losses of $93 million (Howitt, Medellín-Azuara, & Macewan, 2014). Physical water risks may also arise due to biological or chemical quality degradation. This problem has been projected to increase in future due to the impacts of climate change (Van Vliet et al., 2013).

Regulatory risk refers primarily to reallocation of supply by water authorities to other sectors or environmental uses. Globally, more than 70% of water withdrawals are for agricultural use (FAO, 2017), and agriculture has been identified as the cause of water depletion in many river basins (Vörösmarty et al., 2010). Consequently, water resource management policies, such as the EU Water Framework Directive (EC, 2000), often encourage the reduction of water use in agriculture in order to release, or secure, water for other sectors (especially the environment) through removal, restriction or modification of water rights. In times of drought, temporary restrictions of water withdrawals for agriculture are usually enforced before physical water scarcity becomes a constraint in order to protect access to water for higher priority sectors. In this way, the FF&V value chain is exposed to a regulatory risk that increases with physical water scarcity.

A *reputational risk* can arise from actual, or perceived, negative impacts of production on local water scarcity. In the UK, articles have appeared in the national press linking withdrawal of water for FF&V to negative impacts on water supply for local communities (e.g., production of Peruvian asparagus, Lawrence, 2010) or environmental degradation (e.g., Spanish strawberries, Fotheringham, 2012). These reports may influence consumer demand or lead to litigation risk which could ultimately remove a business's 'licence to operate' in a particular locality. Such reputational risks are likely to increase as growing over-exploitation of water resources has negative impacts on other water users and the ecology.

By far the greatest volumes of water used in the value chain for FF&V are associated with growing crops (Mekonnen and Hoekstra, 2011). As such, in this article we focus predominantly on these three types of risk in the location of production.

Water for FF&V production may be supplied by rainfall ('green' water) or as water withdrawn from rivers, lakes and groundwater ('blue' water) (Falkenmark, 1995). Rainfed crops are exposed to weather variability and climate change risks; these have been considered elsewhere (e.g., Knox, Daccache, Hess, & Haro, 2016; Knox, Hess, Daccache, & Wheeler, 2012), and are beyond the scope of this study. However, as blue water has alternative and competing uses, in this paper, we focus on the risks associated with the use of blue water in the growing of FF&V.

Blue water is primarily used for irrigation of FF&V, although very small quantities are also used for other production-related on-farm activities, such as crop spraying. The increasing reliance of FF&V on irrigation reflects the global drive to increase production efficiency and marketable yields; the high quality standards demanded by retailers and consumers; and the increasing range of crops being grown under cover. Blue water used to produce certain types of FF&V can have very high economic returns (up to 10$/m^3 of blue water for vegetable crops grown under plastic out of season in Spain, far exceeding values for field crops), which helps explain trends towards increasing irrigation use for some types of FF&V (Fereres, Goldhamer, & Parsons, 2003).

FF&V makes a major contribution to the total blue water requirement of many diets. Fruit and vegetables (excluding potatoes) were estimated to account for 30% of the blue water required to support the diet of the UK (Hess, Andersson, Mena, & Williams, 2015). Although they exert a smaller overall impact on global water consumption than cereals due to their lower overall production levels, fruit and vegetables have the highest average water footprint per calorie compared with other crop types (with the exception of nuts and spices) (Mekonnen and Hoekstra, 2011). Additionally, the higher value of fruit and vegetable crops can stimulate greater shifts to their production in circumstances where water scarcity is driving up irrigation costs. In some instances this can have the perverse impact of driving up irrigation requirements further, as has been found for citrus in Spain (Fernandez Garcia, Rodriguez Diaz, Camacho Poyato, Montesinos, & Berbel, 2014).

Per capita FF&V consumption in the UK is among the highest in Europe, with 46% of the population consuming one to four portions per day and a third consuming more than five portions per day (Eurostat, 2018), but it has a negative FF&V trade balance and relies on imports (especially for exotics and out of season crops). In this paper we aim to identify where, geographically, the UK FF&V system is reliant on blue water resources and where it is most exposed to physical and related water risks ('hotspots'). We also identify how these have changed over the 20-year period 1996–2015.

Although there is no dataset summarizing the likelihood and severity of regulatory water risks in the form of water restrictions by production location, the degree of regional water scarcity for the production origin can be used as a proxy. Businesses that use blue water withdrawn from water scarce river basins are at a higher regulatory risk than those which use water from basins where water is plentiful (Schulte & Morrison, 2014).

This paper posits that the exposure of the UK FF&V system to physical and regulatory water risks can be inferred from the volume of blue water that is consumed in growing fruit or vegetables at a particular location and the relative abundance, or scarcity, of freshwater resources at that location. Businesses that consume large volumes of blue water in water-scarce locations are exposed to greater water risks than those that consume little or are located in basins where water is plentiful. Reputational risks are also higher in such locations as the potential damage to ecosystems and livelihoods is higher where water is scarce. The blue water scarcity footprint, WSF, is the product of the volume of blue water consumed in production and an indicator of local water scarcity. It provides an indication of the potential impact of an activity on blue water scarcity (ISO, 2014) and, from the above, it can be used as a proxy for the exposure of this point in the value chain for the product in question to physical, regulatory and reputational water risks.

Method

Supply of FF&V to the UK

In this study, FF&V includes products traded into the UK, based on those categorized in the 8-digit EU Combined Nomenclature (CN) (COEC, 1987) as Edible Vegetables (07) or Edible Fruits (08) – with the exception of products that are provisionally preserved, dried or frozen; nuts; crops grown for beverages; and crops grown for industrial processes (e.g., potatoes for manufacture of starch, grapes for wine, chillies for capsaicin or olives for oil production). The CN is based on the 6-digit Harmonised System (HS), used by the majority of trading nations, but with some categories subdivided to provide greater detail.

However, even within the CN, not all fruits are differentiated between fresh and dried (e.g., CN 08052010 does not differentiate between fresh and dried clementines). It is likely that the volumes of dried fruits in these categories that are imported are small and therefore the error introduced can be ignored. Potatoes are categorized in the CN as vegetables, but as starchy carbohydrates they may be considered to belong in a different class to other fresh vegetables. For this reason potatoes have been presented separately from other categories of vegetables in this paper.

We used UK government trade statistics (HMRC, 2017) over the period 1996 – 2015 to identify the volumes of FF&V supplied to the UK by trade, to map the quantities coming from each trading partner, and to determine how this has changed over time. Data on the annual total net mass of imports (including arrivals from the rest of the EU) to the UK from all trading partners was obtained for each specified FF&V category. The top categories were selected (see supporting information), which between them, accounted for 94.0 – 96.5% (by net mass) of FF&V traded into the UK in any year. The categories that were excluded comprized less common types of FF&V that are only supplied to the UK market in small quantities and would thus be unlikely to exert a major influence on the broad-scale water risks to the UK supply.

A proportion of the UK's FF&V supply is imported from countries that do not grow the crops themselves but are intermediaries. For example, the Republic of Ireland provides 6% of the UK's supply of bananas (HS 08039010), but given environmental production requirements they are clearly not grown there. To address this issue, re-exports to the UK from trading partners providing more than 5% (on average) of the UK's supply of an FF&V category – which for a range of types of FF&V included the Netherlands, Germany, Belgium and the Republic of Ireland – were traced back to their likely country of origin using data sourced from the United Nations Comtrade database (United Nations, 2016). Because Comtrade provides data in the 6 digit HS format rather than the 8 digit CN format it was necessary to work on the assumption that sourcing patterns would not be substantially different for the less disaggregated categories represented by the HS categories. For FF&V categories where intermediary trading partners were providing re-exported FF&V to the UK that constituted less than 5% of the UK's total supply for that category, the trade data was not traced back. Instead the overall proportional distribution of trade from producing countries for the whole dataset for that FF&V category was used as a substitute to determine the re-allocation of data from the intermediary trading port to countries of origin.

Domestic production for the relevant FF&V categories was obtained from the Department for Environment, Food and Rural Affairs' 'Horticulture statistics 2015' (DEFRA, 2016). In some cases the categorization of FF&V products did not align perfectly with the CN trade categories, however the differences in categorization were small. As such, the assumption was made that resulting inaccuracies in the analysis would not be large enough to substantially affect the outcomes of the analysis. The selected import categories and domestic production accounted for ≥ 97% of the FF&V available in the UK in any year.

Total annual exports and dispatches from the UK to the rest of the world (not broken down by trading partner countries) for each FF&V category were also obtained (HMRC, 2017). The supply of FF&V to the UK is defined as the sum of domestic production and imported produce, less the FF&V exported from the UK. To account for small year-to-year changes in sourcing, the average of 2011 – 2015 was taken as a baseline period that can be considered representative of the current sourcing of the UK's FF&V supply. To normalize for growth in supply due to increasing population, the totals were divided by the population of the UK.

Blue water consumption

Consumptive water use refers to the blue water that is removed from a drainage basin to which it is not returned, either due to evaporation, transpiration, integration into produce, or because it is released into a different basin or the sea (ISO, 2014). Where water is used but not consumed, it is returned to the same drainage basin and is thus available for other uses and users in times of water scarcity. The quantity of blue water consumed in the production of FF&V depends heavily on environmental conditions in the production location which determine the total water requirement and the need for irrigation. For example, the average blue water consumption of 1 kg of fresh potatoes grown in the UK is 11 litres (Hess, Lennard, & Daccache, 2015) whereas for production of the same quantity in Egypt an average of 290 litres is required (Mekonnen and Hoekstra, 2011). Therefore, estimates of the specific blue water consumption (l/kg) of products grown in different countries (Mekonnen and Hoekstra, 2011) have been used with the trade data to estimate the blue water consumption (*BWC*, l/year) associated with the supply of FF&V to the UK.

$$BWC = \sum_{p=1}^{p=n} \sum_{c=1}^{c=n} W_{p,c} M_{p,c}$$

Where $M_{p,c}$ is the mass (kg/year) of product, p, sourced from country, c and $W_{p,c}$ is the specific blue water consumption (l/kg) for that product and country. As Mekkonen and Hoekstra (2011) did not consider mushrooms, a specific blue water consumption of 9 l/kg was used for all locations (Robinson, Winans, Kendall, Dlott, & Dlott, 2018).

Water scarcity footprint

There are several sources of global estimates of water scarcity indicators at national or basin scales (see Liu et al., 2017 for a review). Boulay et al. (2017) present a method ('AWARE') for assessing water scarcity based on the relative available water remaining once the demand of humans and aquatic ecosystems has been met, based on modelled average runoff for 1960 – 2010. The resulting factor ranges between 0.1 and 100 and has been summarized at basin and national scale for agricultural and non-agricultural water use. A factor of 1 represents global average water scarcity whereas a factor > 1 represents increasing degrees of water scarcity. In this study, the water scarcity footprint (*WSF*, m^3 H_2O_e), in accordance with ISO (2014), is determined from

$$WSF = \frac{\sum_{p=1}^{p=n} \sum_{c=1}^{c=n} W_{p,c} M_{p,c} CF_c}{1000}$$

Where CF_c is the water scarcity characterization factor for agricultural water use in country c, (Boulay et al., 2017). The resulting water scarcity footprint is in 'water equivalent' (m^3 H_2O_e) where 1 m^3 H_2O_e can be thought of as having the same impact on water scarcity as 1 m^3 of water withdrawn from a basin at the global average level of water stress. Although the absolute numbers have no physical meaning, this provides a useful indicator for comparing the exposure of products and locations to water scarcity. A product with a large water scarcity footprint will be one where there is a coincidence of a large mass of production for the UK market, a high blue water requirement per unit of production and a water scarce location.

Small volumes of certain products are imported from countries for which no values of $W_{p,c}$ are presented in Mekonnen and Hoekstra (2011). Where a value has been given for green water consumption, it is assumed that the crop is rain fed and a value of zero has been assigned to $W_{p,c}$. Where no data are given for green or blue water it is assumed that the product is not grown in that country and has been sourced from a third country. In this case, the global average $W_{p,c}$ for that product has been used. For products sent out from the UK it has been assumed that the export crops have been domestically grown and the $W_{p,c}$ for the UK has been used, although there is likely to be some re-export of imports (e.g., an average of 20 mil kg of bananas were exported annually (2011–2015) which were not grown in the UK).

Results

Supply of FF&V

The average (2011–2015) supply of FF&V to the UK is 211 kg/capita/year, with 27% of this coming from fruit, 30% from vegetables, and 43% from potatoes (Table 1). Only 10% of the fruit is grown in the UK whilst 40% is imported from the Americas, particularly South (20%) and Central America (14%). Half of the vegetable supply is home-grown with the majority of the imported crop (41%) coming from Europe, whereas 94% of the potato supply is from domestic production. Only 3% of the FF&V available in the UK is exported, half of which is potatoes.

Blue water consumption

The net blue water consumption of the supply of FF&V to the UK is 560 million m^3/year (Table 1), 62% of which is associated with fruit production and only 26% is water

Table 1. Supply of fresh fruit and vegetables, kg/capita/year, and blue water consumption, million m^3/year, of fresh fruit and vegetable supply to the UK (2011 – 2015).

	Supply (kg/capita/year)				Blue water consumption (million m^3/year)			
Region	Fruit	Vegetables	Potatoes	Total	Fruit	Vegetables	Potatoes	Total
UK	5.8	35.4	87.2	128.4	23	38	85	146
Africa	9.7	2.0	0.2	11.9	122	9	4	135
Americas	23.3	1.4	0.0	24.8	79	4	0	83
Asia	1.2	0.9	1.2	3.3	19	3	7	29
Europe	18.2	25.7	3.7	47.6	115	63	4	182
Oceania	0.8	0.2	0.0	1.0	1	0	0	1
Source unknown	0.0	0.0	0.0	0.0	0	0	0	0
Sent out from UK	−1.8	−1.3	−2.9	−6.0	−12	−2	−3	−17
Total	57.1	64.4	89.4	211.0	347	116	97	560

consumed from domestic water resources. As such, three-quarters of the water consumed in the production of FF&V supplied to the UK is consumed in other countries, particularly Spain, South Africa and Egypt (Figure 1(b)).

Blue water scarcity footprint

The total blue water scarcity footprint of the supply of FF&V to the UK is 26,100 million m^3 H_2O_e/year. Although the UK accounts for 26% of the blue water consumption, it has much lower water stress than many of the countries from which it imports FF&V. Therefore, it accounts for only 3% of the total blue water scarcity footprint (Table 2) associated with the

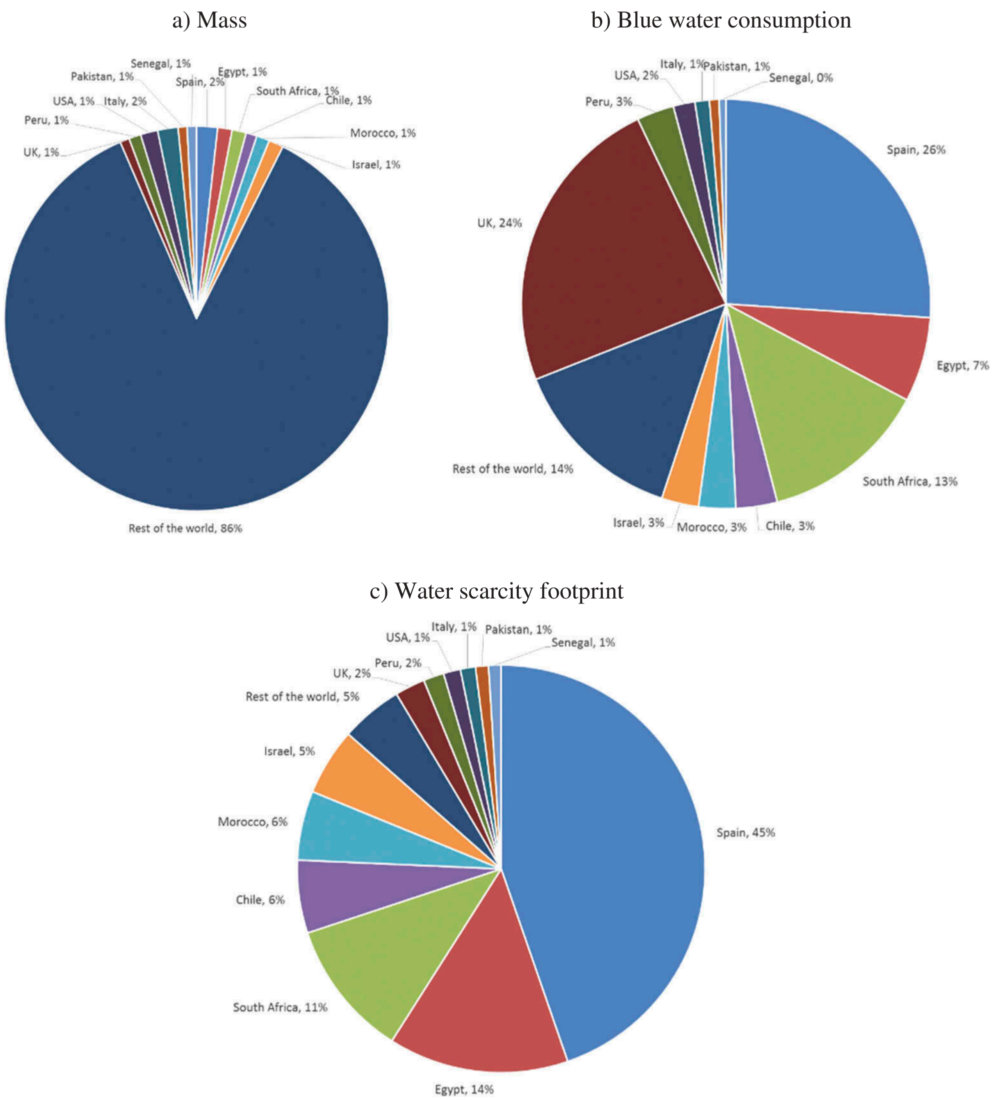

Figure 1. Average (2011 – 2015) a) sourcing of fresh fruit and vegetables to the UK, b) blue water consumption, and c) water scarcity footprint by country.

Table 2. Relative blue water scarcity footprint of fresh fruit and vegetable supply to the UK (2011 – 2015) by region.

Region	Fruit	Vegetables	Potatoes	Total
Europe	30%	17%	1%	48%
Africa	27%	3%	2%	32%
Americas	10%	1%	0%	10%
Asia	5%	1%	2%	8%
UK	0%	1%	2%	3%
Total	72%	22%	6%	100%

supply of FF&V. The largest blue water scarcity footprint is associated with fruit (30%) and vegetables (17%) from Europe and fruit from Africa (27%). Over a third of the total blue water scarcity footprint (36%) is associated with citrus (especially oranges and citrus hybrids), followed by stone fruit (10%: peaches, nectarines, plums) and tropical fruit (9%: avocados and mangoes). The vegetables with the highest blue water scarcity footprint are potatoes (6%), onions (4%) and cauliflower & broccoli (4%).

Seven countries account for 90% of the blue water scarcity footprint of the supply of FF&V to the UK (Figure 1(c)): Spain (45%: citrus, stone fruit, salads, cauliflowers & broccoli, onions), Egypt (14%: citrus, potatoes), South Africa (11%: citrus, pome fruit, stone fruit, avocados), Chile (6%: avocados, blueberries, apples), Morocco (6%: citrus, tomatoes); Israel (5%: potatoes, avocados, citrus, mangoes) and Peru (2%: mangoes, avocados, citrus) with domestic production only accounting for a further 3% (potatoes).

Changes in WSF over time

As a result of changing diet and sourcing, the per capita blue water scarcity footprint of the supply of both fresh fruit and vegetables to the UK has been increasing over the 20 year period (1996 – 2015) whilst that of potatoes has been reducing (Figure 2), primarily due to the increased substitution of potatoes by pasta and rice in the UK diet (DEFRA, 2018).

There has been a 32% increase in the per capita blue water scarcity footprint associated with fruit between 1996–2000 and 2011–2015, which can largely be explained by an increase in fruit supply (Table 3), and has resulted in increases in the blue water scarcity footprint associated with imports from Spain (citrus, stone fruit), Egypt (citrus) and Chile (avocados, blueberries) (Figure 3).

Across the vegetable category, between 1996–2000 and 2011–2015 domestic production of vegetables (excluding potatoes) has fallen by 30 kg/capita/year, which has almost entirely been compensated by increased imports from Spain and Netherlands. Less blue water is consumed in the production of vegetables in the UK (average 21.2 l/kg) and Netherlands (8.9 l/kg) compared to Spain (72.7 l/kg). In addition, although the water scarcity characterization factor for Netherlands is one-third of that of the UK, the value for Spain is 17 times that of the UK. Thus any shift to sourcing from drier and more water scarce countries results in an increase in blue water scarcity footprint. Consequently, although the supply of vegetables per capita increased by only 7%, the 62% increase in blue water scarcity footprint per capita was due to a shift in sourcing, with increases attributable to the greater reliance on vegetables sourced from Spain (salad crops, cauliflower and broccoli), Egypt (beans, onions), Senegal (sweetcorn) and Morocco (tomatoes) (Figure 4).

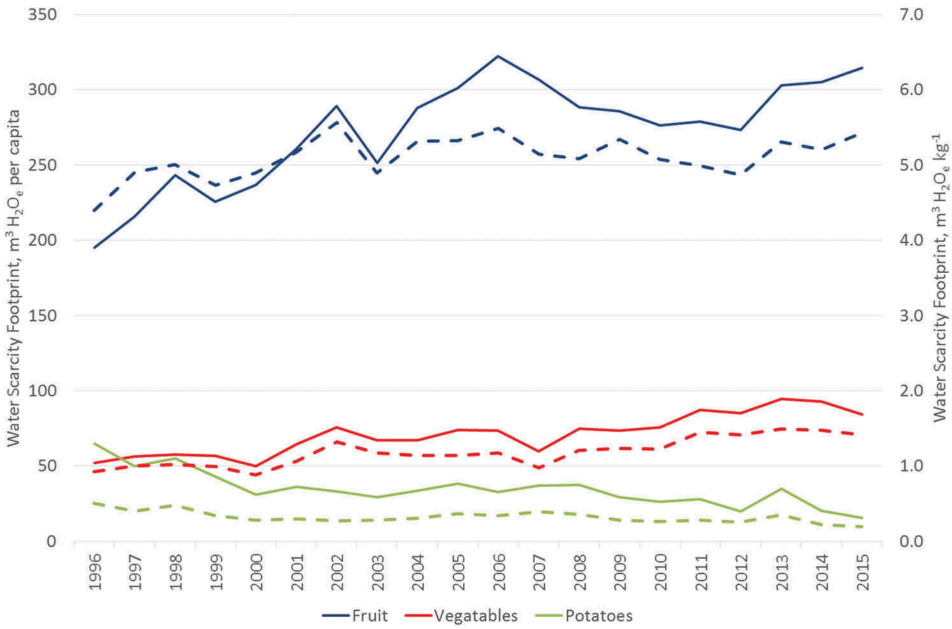

Figure 2. Change in water scarcity footprint of fresh fruit and vegetable supply to the UK (1996 – 2015) per capita (solid line) and per kg (dashed line).

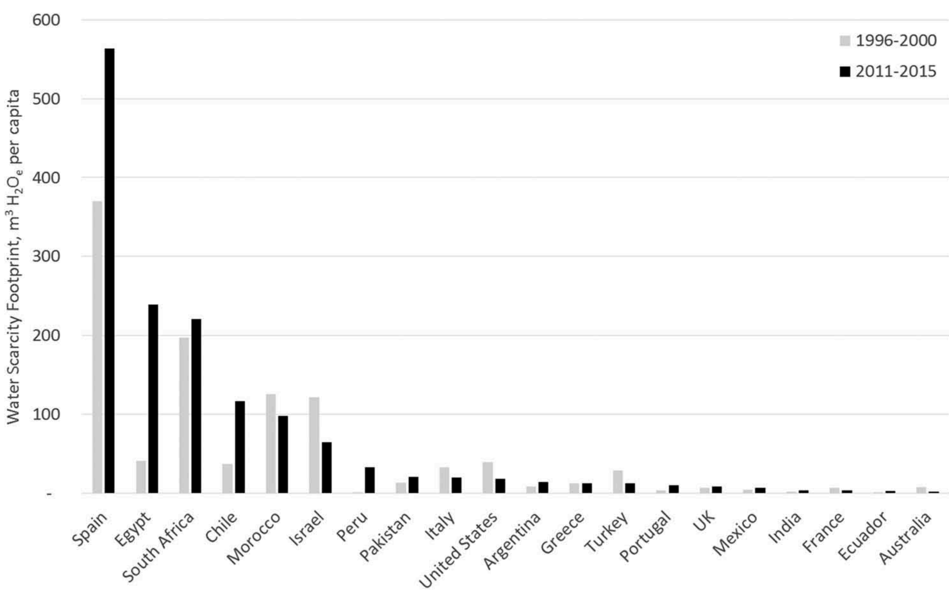

Figure 3. Change in water scarcity footprint of fruit supply to the UK between 1996–2000 and 2011–2015, m^3/capita/year showing top 20 countries by source.

In contrast, the reduced blue water scarcity footprint per capita for potatoes has been associated with a reduction in supply from 121 to 89 kg/capita/year. This has mostly come from reduced domestic production, but the fact that less is now sourced from

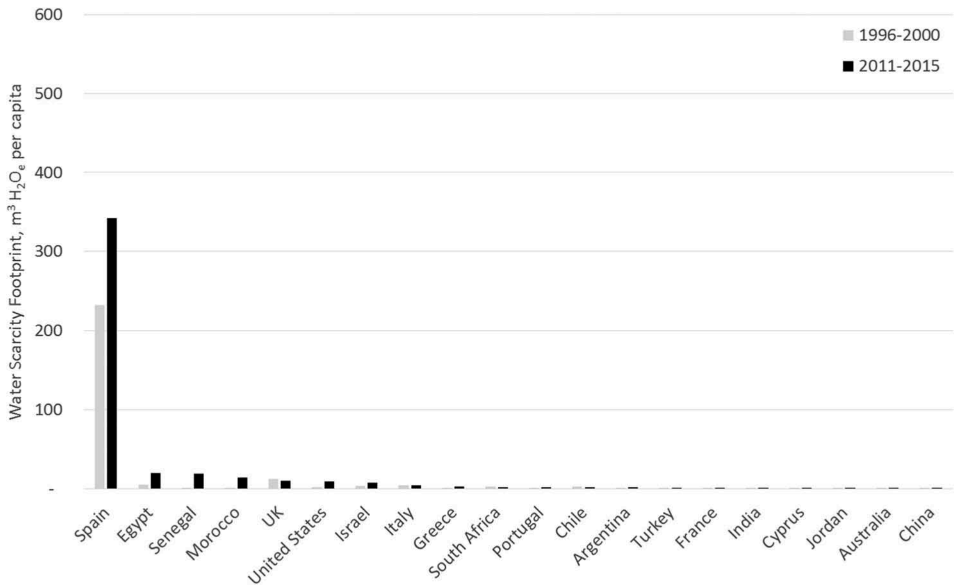

Figure 4. Change in water scarcity footprint of vegetable supply to the UK between 1996–2000 and 2011–2015, m^3/capita/year showing top 20 countries by source.

Table 3. Change in blue water scarcity footprint (m^3 H_2O_e capita/year), supply (kg/capita/year) and blue water scarcity footprint (WSF) per unit supply (m^3 H_2O_e/kg) in 2011–2015 compared to 1996–2000.

	Fruit	Vegetables	Potatoes
WSF, m^3 H_2O_e/capita/year	132%	162%	49%
Supply, kg/capita/year	123%	107%	74%
WSF, m^3 H_2O_e/kg	108%	151%	66%

Egypt, where there is a large water scarcity characterization factor, has also contributed a little to the reduction in WSF per kg.

Discussion

From this analysis, most of the UK's imports of FF&V are from water stressed countries, suggesting that the UK food system is exposed to a range of physical, regulatory and reputational water risks. Following the definition used in this study, a location with a high water scarcity characterization factor is one where the withdrawal of freshwater for agriculture has a high '… potential to deprive another user … in this region' (Boulay et al., 2017). Therefore water for agricultural production of the UK's FF&V is in high competition with domestic, industrial and/or environmental uses.

Hotspots

Competing demands from the environment characterize the water scarcity situation for some important agricultural areas in Spain. For example, the Murcia region accounts for 20% of Spain's fruit and vegetable exports and is Spain's main producer of broccoli, celery, artichokes, apricots, table grapes, lemons and an important producer of tomatoes and peppers (Catedra UCAM-Santander, 2016). Agricultural production in the area has been intensifying in recent years, with the production of fruits increasing by 54% and vegetables by 27% between 2010 and 2015 (Catedra UCAM-Santander, 2016). Due to the extreme aridity of the local climate, production is heavily reliant on irrigation and the irrigated area has more than doubled since the middle of the last century (Oñate & Peco, 2005). Expansion of the region's canning industry coupled with severe drought in the early nineties led to both declining river flow and increasing industrial and urban wastewater discharges; a combination which resulted in severe pollution that decimated aquatic life and caused river bank degradation along large stretches of the Segura River. The public outcry that ensued led to the development of a 10 year management strategy for improving river management and significant ecological recovery has since taken place (Ródenas & Albacete, 2014). Nonetheless, continued pressure on the water resources of the region, partially attributable to production of fruit and vegetables for export, has led analysts to suggest that there is a risk of environmental and economic collapse if further new measures are not adopted to correct the effects of over-exploitation (Ruperez-Moreno et al., 2017). In this case, there is a chronic water scarcity risk to FF&V exports to the UK.

South Africa provides an example where water use for agricultural production for fruit exports is in severe competition with domestic use (Van Dam, 2017), particularly given the drought-prone nature of the region. The Western Cape province of South Africa is a major producer of export fruits for the UK, but since 2015 has been facing the combined effects of a severe drought and a strong El Niño event (Baudoin, Vogel, Nortje, & Naik, 2017). At the time of writing it is estimated to be the worst drought in over a 100 years (Van Dam, 2017). The delayed onset of winter rainfall in 2017, the high demand for water by growing urban populations and the cumulative rainfall deficit have led to the imposition of water restrictions in cities across South Africa, including Cape Town and Johannesburg (Baudoin et al., 2017; Sorensen, 2017). Farmers have been forced to reduce the irrigation of fruit orchards and take lower-yielding areas out of production altogether (Dentlinger, 2017; Jansen, 2017). Water restrictions for irrigating farmers vary from 30% to 100% in some catchments, which may have a serious impact on fruit production (Jansen, 2017). It was estimated in 2016 that the South Africa deciduous fruit industry lost ZAR720 million (≈ US$50 million) and in 2017 apple exports were down by 9% (Chambers, 2017; FruitSA, 2016). Whilst drought is a recurrent feature of South Africa's climate, its impacts on the region and the fruit sector are likely to worsen in future (Jansen, 2017), highlighting an urgent need for appropriate resilience-building measures within the FF&V value chain.

Future change

The climate in many producing regions is projected to become more unpredictable, which, when coupled with increased local demand for domestic, industrial and environmental water, is likely to lead to increased water scarcity and probability of drought. Higher temperatures will raise evapotranspiration rates and therefore irrigation demands, areas dependent on snowmelt may find the seasonal timing of water availability shifts substantially, and sea level rise coupled with increasing abstraction will likely lead to the salinization of coastal aquifers (Morison, Baker, Mullineaux, & Davies, 2008). Population growth will drive increased demand for food in the UK (as well as increased competition for food from growing and rapidly changing economies) and per capita consumption of FF&V has been increasing (Figure 2). Greater recognition of the health and environmental benefits of diets lower in processed foods, sugars and animal fats is likely to further drive up FF&V consumption in the near future, but a move to more healthy and/or vegetarian diets has been associated with an increase in blue water consumption in the UK (Hess, Andersson, et al., 2015), the USA (Tom, Fischbeck, & Hendrickson, 2016) and the EU (Vanham, Mekonnen, & Hoekstra, 2013). All these factors are likely to drive increases in the exposure of the UK's FF&V system to physical water risks in future.

Limitations and uncertainty

The estimates of specific blue water consumption for fruit and vegetable products have, necessarily, been modelled from agroclimatic data. Implicit in our assumptions is that all crops that require irrigation are actually irrigated. Mekonnen and Hoekstra (2011) concluded that when combined with national production data, and allowing for irrigation efficiency, their estimations of blue water consumption agreed well with recorded withdrawals for irrigation at national level. However, there may be large uncertainties for individual countries. For the water scarce countries that make up the hotspots of the UK's FF&V value chain, the assumption of full irrigation may be reasonable, however, in temperate climates the actual blue water consumption may be less as it may be uneconomic to irrigate crops with a small irrigation demand. For example, the estimated blue water consumption for the UK is 144 million m^3/year compared to an estimated irrigation amount of 125 million m^3/year (after Knox et al., 2015; Brown et al., 2012; and Northern Ireland Environment Agency, personal communication, 18 August 2017).

Based on the availability of trade data at the national level, water consumption and water scarcity have also been estimated at the national level. For large countries and those with diverse climates and water resource conditions this may obscure local conditions. Hess, Lennard, et al. (2015) have shown how broad-scale estimates of water scarcity footprints obscure local issues. For example the specific blue water consumption of oranges from South Africa vary between the Northern Cape province (279 l/kg) and KwaZulu-Natal province (116 l/kg) (Mekonnen and Hoekstra, 2011) whilst the Aware water stress factors are 20.1 and 5.5 respectively (Boulay et al., 2017). Thus the blue water scarcity footprint of 1 kg of oranges from Northern Cape Province is almost nine times greater than for 1 kg from KwaZulu-Natal. It was not possible to reflect these sub-national variations in water scarcity in the present study since regionally disaggregated trade data for the original production locations of the UK's FF&V supply was not available. Similarly, using an annual resolution may obscure seasonal variation in blue water demand and availability. However, whilst the trade and water scarcity information are available at a monthly resolution, the global dataset of blue water demand for all crops is only available at an annual scale. A final limitation is that, based on the sourcing data used, it is not possible to know what proportion of blue water used in each location was derived from different water sources, e.g., river, reservoirs, or groundwater, which will be exposed to differing degrees of risk.

Conclusion

13.5 billion kg of fresh fruit and vegetables are supplied to the UK each year, equivalent to 211 kg/capita/year. Of this, the UK imports 90% of the fruit and 50% of the vegetables (excluding potatoes). Growing these products consumes 560 million m^3 of freshwater per year, 74% of which is withdrawn overseas, often in countries where water resources are under pressure and drought risks are high. As a consequence, the supply of FF&V to the UK is exposed to physical, regulatory and reputational water risks in other countries as well as at home.

The locations where large volumes of water are consumed in the production of FF&V for the UK and water is scarce have the highest potential water related risks. By this logic, the UK FF&V system is particularly exposed to potential water risks in a small number of countries. Seven countries account for over 90% of the blue water scarcity footprint associated with the FF&V imported to the UK. As such, Spain (46%), Egypt (15%), South Africa (11%), Chile (6%), Morocco (6%), Israel (5%) and Peru (2%) constitute 'hotspots' where the volume of water consumed is high and water is scarce.

Over the 20 years from 1996 – 2015, the exposure of the UK's FF&V system to physical, regulatory and reputational water related risks has increased by 36% due to a combination of increased consumption of fruits that cannot be grown in the UK (especially avocados, citrus fruits and mangoes) and changes in the location of sourcing (especially a shift from domestic production to imports; predominantly from Spain). Regarding domestic production, potatoes are the product with the highest potential water related risk, but the supply of potatoes has declined dramatically over the last 20 years resulting in a lower overall water risk for domestic FF&V production. In future, growing demand for FF&V coupled with reductions in water availability (both domestic and overseas) will likely further increase the exposure of the UK's FF&V supply chain to physical, regulatory and reputational water risks and place more pressure on already stressed aquatic environments in countries that produce the bulk of the UK's supply.

There are differing potential responses to a high water risk in a FF&V supply chain. In some cases, the risk may be considered so high, that, in the long-term, alternative sourcing locations (with lower water risks) may be sought. However, this is often a last resort as resilient supply chains take a long time to establish; it may result in unacceptable social impacts on local livelihoods; and may be seen as simply offloading the problem onto others. A more sustainable approach may be to engage in catchment level-water stewardship to increase resilience to water risks. Finally, consumers may express a preference for more sustainably produced FF&V and, provided they have sufficient information to make rational choices, may prioritise certain products over others.

Whilst this global study has identified potential 'hotspots' where water risks in the FF&V value chain may be high, the coarse spatial and temporal resolution and the wide range of grower responses to water risks (e.g., through water conservation or waste-water reuse) means that local studies are needed in these areas in order to formulate water resilient supply chains.

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