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The water footprints of global food and agriculture trade

Why the 'virtual water' use hidden in supply chains is critical to sustainability

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Summary

- Food systems are the dominant user of freshwater resources, accounting for almost 70 per cent of global freshwater withdrawals. International trade in food and agricultural products effectively transfers vast volumes of 'virtual water' used throughout supply chains to consumer markets, where the impacts of the water use embedded in products are often invisible to consumers. This paper traces the sustainability challenges associated with this trade, and provides ideas for improvements in water governance.

- Trade, theoretically, allows for a more balanced use of the world's water resources by enabling water-scarce countries to access water-intensive products from water-plentiful regions – and for both parties to profit from the exchange. However, in practice a combination of overextraction of resources, underpricing and weak regulation in many countries often results in water-intensive products coming from water-scarce and/or climate-vulnerable regions.

- In such cases, the production of commodities for export can have significant negative consequences for water resources in the exporting country – including by causing water pollution, diversion and depletion, and by reducing society's resilience to climate and biodiversity crises. Growing populations, rising living standards and shifting dietary preferences, coupled with a corporatized international trading system, have dramatically increased the water footprints of the food and agricultural sector in recent decades, exacerbating water stress in many producer regions and creating significant geopolitical and supply-chain risks.

- Ensuring the water footprints of food and agricultural trade are sustainable and resilient is an increasing national security concern. Achieving that aim depends not only on actions by farmers and within specific river basins, but on international investors, trading governments and retailers of food products transforming how they interact with – and value – water. Progress towards sustainable virtual water governance in the food and agriculture sector can be driven by:

  - Policy interventions that are coordinated across government ministries, between producer and consumer countries, and involve the public and private sectors, aiming for synergies between water-related, climate and biodiversity actions.

  - Reforming or repurposing agricultural subsidies, including those that directly promote water-intensive irrigation in water-stressed regions or support the overuse of inputs. Addressing these subsidies should be prioritized as they prevent the true value of water from being reflected in pricing.

  - Importing countries supporting sustainable water use in overseas stages of supply chains by mandating water footprint disclosures, and by instigating due diligence requirements and standards related to the environmental and social impacts of water use and management.

- Importers providing support to supplier countries to ensure that trade measures for sustainability are workable, thereby forestalling accusations of rich-country protectionism.
- Plurilateral cooperation, such as through high-level forums like the World Trade Organization (WTO)'s Trade and Environmental Sustainability Structured Discussions (TESSD). Such cooperation offers possibilities for building trust and improving engagement between trade partners on water concerns.

Preface

At the 2021 United Nations Climate Change Conference, COP26, a coalition of 23 governments (including the host nation, the UK), businesses and civil society organizations signed the **Glasgow Declaration for Fair Water Footprints for Climate-Resilient, Inclusive, and Sustainable Development**. Signatories resolved to 'take transformative action for fair water footprints which will have durable benefits for our communities, ecosystems, and economies, and help to achieve Sustainable Development Goal 6 (SDG 6): Ensure availability and sustainable management of access to water and sanitation for all by 2030'.[1] This minilateral, multi-stakeholder initiative aims to demonstrate commitment to good water stewardship, promote best practice, and have its principles considered and taken up in a broader set of forums, including existing multilateral processes.

The Glasgow Declaration is based on shared recognition that the 'water footprints' (i.e. the direct and indirect water use – see Box 2) of consumer society, economic activity and international trade are tightly connected, including through global supply chains. Signatories identify the shared obligation of consumers, producers, trading partners, industry, investors, financiers and retailers to ensure sustainable and equitable water use.

Water governance is not only a matter for those concerned with local river basin management or in-country economic development. It is a cross-border and global issue affecting multiple aspects of international relations.

Underpinning this commitment is the principle that water governance is not only a matter for those concerned with local river basin management or in-country economic development, as is often perceived to be the case. It is also a cross-border and global issue affecting multiple aspects of international relations. The consequent need for a global approach to water governance is exemplified by the fact that the water footprints of many high-income nations are 40–80 per cent external, meaning that such countries are highly reliant on water use elsewhere in the world for the production and delivery of imported goods.[2]

1 Fair Water Footprints (2021), 'The Glasgow Declaration for Fair Water Footprints for Climate-Resilient, Inclusive, and Sustainable Development', p. 3, https://fairwaterfootprints.org/resource/declaration-in-full/fwf_glasgow_declaration_rebrand_proof_01.
2 Chapagain, A. K. and Mekonnen, M. M. (2023), 'Understanding the water footprints of the Global North and dependency on water use within the Global South', Water Witness International, https://fairwaterfootprints.org/resource/towards-fair-water-footprints-understanding-the-water-footprints-of-the-global-north-and-dependency-on-water-use-in-the-global-south.

Trade potentially allows for a more balanced use of the world's water resources by enabling water-scarce countries to access water-intensive products from water-plentiful countries and regions – and for both parties to profit from the exchange. However, in reality, a combination of overextraction of resources, underpricing and low regulation in many countries often results in water-intensive products coming from water-scarce and/or climate-vulnerable regions. In such cases, the production of commodities for export can have significant negative consequences for water resources in the exporting country, including by causing water pollution, diversion and depletion, and by reducing society's resilience to climate and biodiversity crises. Globally, the safe limits for freshwater use have been transgressed, increasing the risk of unmanageable instability in the hydrological system.[3]

In this context, the Glasgow Declaration defines 'fair water footprints' as those that meet five social and environmental sustainability criteria: zero water pollution; sustainable water withdrawals and equitable allocation of water; protection of nature; access to safe water, sanitation and hygiene; and resilience to droughts, floods, climate variability and water conflict (see Box 1).[4]

This research paper is one of a series of three that explore the water-related impacts of global trade in different sectors. The sectors are: food and agriculture; textiles; and mining of critical metals and minerals for the technology industry. These sectors were chosen because all have significant international water footprints, are often particularly thirsty and polluting, and are increasingly affected by (and themselves affect) climate change and other environmental challenges. Each paper provides a concise overview of what is known about that sector's water footprint, highlighting the global trade dependencies between producer and consumer countries. The papers provide an overview of how global trade is contributing to, or undermining, prospects for realizing the Glasgow Declaration's ambition for 'fair water footprints' in each sector. At the same time, they examine how trade partnerships can serve countries' strategic security interests and – at both national and multilateral levels – strengthen water-related policy and practice.

Chatham House is a member of the Fair Water Footprints partnership[5] alongside CDP, the International Institute for Environment and Development, Water Witness International, and the UK government's Foreign, Commonwealth and Development Office (FCDO). Together we are working with signatories to the Glasgow Declaration to drive progress towards the ambitions of the declaration.

3 Richardson, K. et al. (2023), 'Earth beyond six of nine planetary boundaries', *Science Advances*, Vol. 9, Issue 37, https://www.science.org/doi/10.1126/sciadv.adh2458.
4 Fair Water Footprints (2021), 'The Glasgow Declaration for Fair Water Footprints for Climate-Resilient, Inclusive, and Sustainable Development'.
5 Fair Water Footprints (undated), 'Frequently asked questions', https://fairwaterfootprints.org/faqs-glasgow-declaration-for-fair-water-footprints.

Box 1. Fair water footprints

The Glasgow Declaration defines fair water footprints[6] as direct and indirect water use that demonstrates:

- **Zero water pollution.** No adverse impacts on the aquatic environment or other water users or functions arising from wastewater discharges. Diffuse pollution is controlled to improve the aquatic environment.
- **Sustainable withdrawal and equitable allocation of water.** Water abstractions and use are within sustainable limits and do not compromise the human right to water, adversely affect downstream needs, or imperil the water security of future generations. This criterion is focused on 'blue water' impacts – that is, those affecting streams, rivers, lakes, aquifers etc. (see Box 2 for definitions of terminology).
- **Protection of nature.** Ecosystems and their services are valued and protected; nature-based and regenerative solutions are prioritized. This criterion encompasses 'green water' (essentially, soil moisture – see Box 2) and blue water uses.
- **Access to safe water, sanitation and hygiene.** Within the workplace, all workers have access to reliable and safe drinking water, toilets and washing facilities; collective action reaches communities in need.
- **Resilience to droughts, floods, climate variability and water conflict.** Effective planning, policy and investment support resilience to climate change, water-related disasters and conflict.

Introduction

When a shopper walks into a supermarket almost anywhere, they will typically find a multitude of imported foods and produce from all over the world. Behind this abundance and choice is a system of international supply chains – largely invisible – linking farmers and fields in producer countries to shops in destination markets. To buy a bag of Pakistan-grown rice in a UK supermarket, for example, a consumer is not only reliant on a kilo of grains travelling halfway round the world; that shopper is also indirectly dependent on the resources – land, freshwater, energy, labour – used to produce, process, transport and store it. This resource use can be said to be 'embedded' in the end-product; where that embedded resource is water, this is referred to in the academic and policy literature as 'virtual water'. The overall water-related impacts from the production or supply of a good, or from all production or consumption by a defined actor or within a defined area, make up what is termed its 'water footprint'.

This paper explores the increasing water footprints associated with international food and agriculture trade,[7] and the challenges this presents for water security,

6 Fair Water Footprints (2021), 'The Glasgow Declaration for Fair Water Footprints for Climate-Resilient, Inclusive, and Sustainable Development'.
7 Two forthcoming companion papers will examine the water footprints of trade in textiles and technology-critical minerals respectively.

environmental sustainability and international relations (see Preface for background on the concept of 'fair water footprints'). Pressures on water sources from overexploitation, pollution and a changing climate and hydrological system mean that addressing water scarcity is emerging as a critical environmental challenge. Accounting for the virtual water hidden in traded products, as well as understanding the impacts of water footprints on producers, exporters and importers, is important for improving the sustainability of water use and the security of resource supplies.

Scale is an important part of the challenge. The global food system accounts for almost 70 per cent of freshwater withdrawals, making it the largest consumer of the world's finite water resources. Growing populations, rising living standards and shifting dietary preferences, coupled with a corporatized international trading system, have dramatically increased the water footprints of the food and agricultural sector in recent decades. It is estimated that the trade in virtual water nearly trebled between 1986 and 2022.[8] Although data on the topic are typically compiled on an ad hoc basis by academic researchers – so no official international datasets on water footprints exist – it is reasonable to assume that virtual water demand has continued to grow since 2022.

Given the often-uneven power dynamics between producers and consumers, this paper argues that responsibility for water use cannot be confined to the local level, such as within farms or specific river basins. International investors, importers and retailers of food products will have to transform how they interact with, and value, water, to make trade more sustainable and conducive to environmental and societal resilience.

Responsibility for water use cannot be confined to the local level. International investors, importers and retailers of food products will have to transform how they interact with, and value, water, to make trade more sustainable and conducive to environmental and societal resilience.

Such actors not only influence markets but also bear risks themselves from overexploitation of water. Social tensions over access to and competition for fertile land and freshwater can disrupt exports; so, too, can abrupt government policy shifts intended to conserve water in producer countries. States and corporations that have acquired or have access to foreign land for export-oriented agriculture could be subject to legal challenges over worsening local water stress. As well as climate and environmental shocks, political or social tensions could also create or aggravate supply-chain bottlenecks, destabilize prices and

8 Mekonnen, M, et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade', *Nature Reviews Earth & Environment*, 5 (12), pp. 890–905, https://doi.org/10.1038/s43017-024-00605-2.

exacerbate food insecurity globally. As has been seen all too often this century, the impacts of crop failures or trade disruptions in one or more critical places can reverberate worldwide.

Recent geopolitical turbulence – including export restrictions, supply-chain fragmentation and tariff impositions – presents its own challenges and opportunities for food trade and hence sustainable water use. Increasing protectionism could restrict the flow of food products to international markets at the same time as droughts, floods and competition for water reduce harvests and worsen food security. Export restrictions in response to societal or political pressure to improve food security could push up international prices, as was seen in many countries when food price inflation surged owing to concerns around grain supplies following Russia's invasion of Ukraine in 2022. Such crises tend to deepen global inequalities and create conditions for political upheaval and geopolitical tension.[9]

With the above landscape in mind, this paper examines the impacts of global food and agricultural production – with a focus on traded food products – on water security, environmental sustainability and economic resilience. The paper also outlines the food and agriculture sector's global water dependencies and explores how water footprints vary between foods. Two country case studies – covering Morocco and Pakistan – are also presented. These offer examples of how the link between agricultural trade and water security functions in practice, and identify the specific water sustainability challenges each country faces. Finally, the paper identifies gaps in knowledge about water footprints for food crops and agricultural products, and surveys existing literature and emerging tools and standards that could help drive fairer and more sustainable water use.

Food and agriculture's overall water use

Food and agricultural production is critically dependent on, and at significant risk from disruptions to, water availability and the hydrological cycle. More than half of the world's food production occurs in areas where the volume of water stored on or beneath the Earth's surface[10] is projected to decline, with nearly 3 billion people also living in such areas.[11] Agriculture and food value chains are major drivers of water stress. They use enormous volumes of 'green' and 'blue' water: i.e. soil moisture and water from surface or groundwater sources such as springs, lakes, rivers and aquifers, etc. (see Box 2 for definitions). And they require significant volumes of 'grey' water (also see Box 2) to dilute the pollutants they produce. While this water is not lost to the water cycle, its use for food production and its pollution by unsustainable agricultural practices often have negative impacts within the affected river basins. Moreover, when food and agricultural products are traded, they carry this water footprint with them as 'virtual water' (again, see Box 2) – making the water impacts invisible to consumers. This is especially the case when the trade is international.

9 Russell, R. (2022), *Price Wars: How Chaotic Markets are Creating a Chaotic World*, W&N.
10 Total water storage includes blue water in rivers, lakes, groundwater, snow and ice, and green water stored as soil moisture.
11 Global Commission on the Economics of Water (2024), *The Economics of Water: Valuing the Hydrological Cycle as a Global Common Good*, https://watercommission.org/#report.

Box 2. A note on terminology

'Blue', 'green' and 'grey' water
Discussion of the hydrological cycle and freshwater use typically categorizes freshwater according to source or pollution, with each category assigned a colour:

Blue water refers to surface and groundwater stores and flows (springs, rivers, lakes, reservoirs, aquifers). Groundwater includes both renewable and fossil resources, the latter of which are not replenished by the hydrological cycle; this means that fossil water extraction results in a permanent depletion of that resource.

- **Withdrawal of blue water** includes both 'consumptive' and 'non-consumptive' uses:
  - Consumptive water use is defined as use that results in the water not returning to its source. This includes evaporation, the incorporation of water into products, and the return of water to another catchment or sea. Only consumptive use is measured in water footprints.
  - Non-consumptive water use results in water being removed but later returned to its source. This is also known as 'return flow' and is not measured in water footprints.
- **The sustainability of blue water footprints** is measured with reference to water depletion. The measurement reflects the ratio between the blue water footprint (see definition of 'footprints' below) in an area/period and the total available volume of blue water in the same area/period.

Green water refers to soil moisture, which forms the evaporative flow for crop growth or for maintaining natural ecosystems.

Grey water refers to the volume of freshwater required to dilute pollutants or to meet water quality standards for a specific pollutant load. If that volume of water is not available (and in the in the absence of other treatment), then water quality standards are violated.

Water footprints
Water footprints are an indicator of freshwater use. They consider both direct and indirect water use by consumers and producers of goods or services. The water footprint of a consumer of specific goods or services is defined as the total volume of freshwater used to provide the goods or services consumed;[12] the water footprint of a producer of goods and services is defined as the total volume of freshwater used to provide those goods or services. Water use is measured in terms of water volumes consumed (i.e. evaporated or incorporated into a product) and/or polluted per unit of time.

A water footprint can be calculated for a particular product (e.g. for a type of food, textile or critical material, etc.) in relation to any well-defined category of consumer of that product (e.g. an individual, family, village, business, city, province, state or

12 Service-related water footprints have historically reflected small amounts of water consumption, but may become a more meaningful category given that data processing (e.g. for artificial intelligence) entails very high levels of water consumption.

nation), as well as in relation to any producer of that product (e.g. a public organization, private enterprise or economic sector).[13]

Where direct and indirect water footprints are distinguished from one another, the direct water footprint is the water consumed or polluted by the specific actor or in the specific activity in question, whereas the indirect water footprint is the water consumed or polluted in the inputs or supply-chain activities prior to the relevant actor or activity.

A water footprint is a geographically explicit indicator and can be used to understand the water interdependencies that arise between countries through the export and import of goods. However, because it is a purely volumetric measurement, it does not directly convey the sustainability or impacts on water scarcity of water consumption. But the water footprint can be used alongside other measures to ascertain whether water use in a specific location – whether affecting an aquifer, river basin or entire nation – is sustainable. In this way, the impacts of water use on environmental water requirements and water quality can be assessed.

Virtual water

'Virtual water' is the amount of water (blue and/or green) required to produce a good or service, including all the production steps. This is also referred to as the water 'embedded' within a product. For a given product, its blue/green virtual water content is the same as its blue/green water footprint, but the concept of virtual water applies only at the *product* level whereas a water *footprint* can also measure water consumption by a company, region or country, etc. A water footprint can also quantify water pollution impacts. This is known as the 'grey water' footprint. The concept of virtual water is often used in trade contexts, with 'virtual water trade' referring to the exchange of goods and services based on their virtual water content.[14]

Agriculture, including livestock farming, uses practically all soil moisture (green water) that does not seep beyond the root zone in soils to reach the water table and that is not evapotranspired by natural ecosystems. Of the 61 per cent of annual rainfall stored as green water, around 8 per cent – equivalent to 5 per cent of total annual rainfall – is used by agriculture. Approximately 80 per cent of global cropland is rainfed, and this area produces 60 per cent of food (Figure 1).[15] Eight per cent may seem a small proportion of all green water globally, but agriculture's green water use dwarfs that of other economic sectors and can be enormously consequential to the ecology of areas where farming occurs. While water-related investments have historically been directed towards improving control over blue water supplies (through infrastructure such as dams and irrigation channels), the importance of managing green water in soil, plants and forests is becoming better appreciated, as stocks and flows of green and blue water are closely interconnected. Green water stocks in plants and root-zone soil moisture, for example, can be recharged by blue water flowing from a reservoir to an irrigated field; evaporation

13 Fair Water Footprints (2021), 'The Glasgow Declaration for Fair Water Footprints for Climate-Resilient, Inclusive, and Sustainable Development'.
14 Global Commission on the Economics of Water (2024), *The Economics of Water*.
15 Hussain, Z. et al. (2022), 'A Comparative Appraisal of Classical and Holistic Water Scarcity Indicators', *Water Resources Management*, 36 (3), pp. 931–50, https://doi.org/10.1007/s11269-022-03061-z.

from fields, transpiration from crops and seepage into the water table, meanwhile, are all green water flows that drive the water cycle.[16] Green water is also becoming scarcer in critical agricultural production areas as a result of unsustainable farming practices – depletion of soil carbon, for example, reduces the capacity of soils to retain moisture.

Agriculture also accounts for 69 per cent of global blue water withdrawals, whether from surface-water or groundwater sources.[17,18] Irrigation returns less water to riverine and groundwater sources than industrial and municipal uses do. Given that irrigation predominates in water-scarce areas and at water-scarce times of the year, irrigation accounts for 90–95 per cent of scarcity-weighted water use globally.[19]

Of all the blue water that is used for irrigation, 52 per cent comes from unsustainably managed sources.

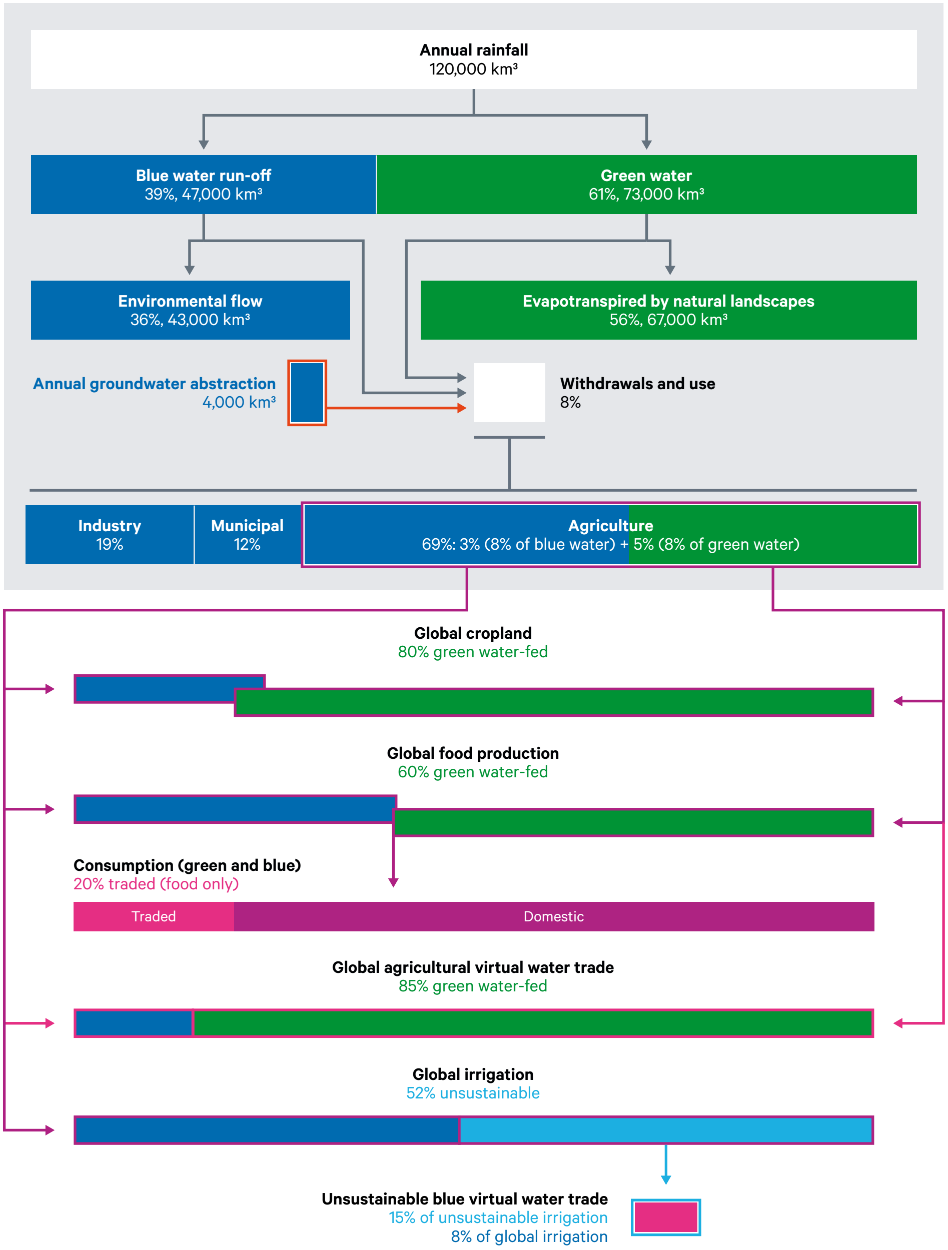
Of all the blue water that is used for irrigation, 52 per cent comes from unsustainably managed sources.[20] These are places where consumption of irrigation water exceeds local renewable-water availability from groundwater and surface water, leading to reduced flows or groundwater levels. Such reductions can cause environmental and social harms such as worsening water quality, habitat fragmentation, loss of biodiversity, and conflict and competition over access to water. Unsustainable water use also limits the capacity of societies and communities to adapt to, or mitigate, climate change and droughts. Further, approximately 20 per cent of all irrigation water is taken from non-renewable groundwater sources. Since these sources are not recharged by the water cycle, this irrigation permanently depletes the affected aquifers.[21]

Global trade accounts for a modest but rapidly growing proportion of food and agriculture's virtual water flows. Currently, about 20 per cent of all green and blue water used in global food production is traded virtually through international markets rather than consumed domestically.[22] International demand has grown particularly quickly, however, for irrigation-dependent crops: such demand now drives 8 per cent of global irrigation water use and 15 per cent of unsustainable irrigation;[23] the unsustainable volume increased by 18 per cent between 2000 and 2015 (most recent available data).[24]

16 Global Commission on the Economics of Water (2024), *The Economics of Water.*
17 This is broadly consistent with Poore and Nemecek (2018), who estimate that two-thirds of global freshwater withdrawals are for irrigation. See Poore, J. and Nemecek, T. (2018), 'Reducing Food's Environmental Impacts through Producers and Consumers', *Science*, 360 (6392), pp. 987–92, www.science.org/doi/10.1126/science.aaq0216.
18 Around 26 per cent of all withdrawals (both for agriculture and in total) are sourced from groundwater. See Margat, J. and van der Gun, J. (2013), *Groundwater around the World: A Geographic Synopsis*, London: CRC Press, http://dx.doi.org/10.1201/b13977.
19 This measure weights volumetric water use by blue water scarcity in the catchment from which the water is abstracted to reflect the potential local environmental impacts of water consumption. The approach is not without its critics – see, for example, Hoekstra, Y. (2016), 'A Critique on the Water-Scarcity Weighted Water Footprint in LCA', *Ecological Indicators*, 66, pp. 564–73, https://doi.org/10.1016/j.ecolind.2016.02.026.
20 Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.
21 Rosa, L. et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade', *Environmental Research Letters*, 14 (11), 114001, https://doi.org/10.1088/1748-9326/ab4bfc.
22 Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.
23 Ibid.
24 Rosa et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade'.

The composition of this trade reflects agriculture's heavy reliance on rainfall: in 2016, green water accounted for 91 per cent of virtual water flows, with blue water accounting for only 9 per cent.[25]

Figure 1. Global green and blue water use by agriculture

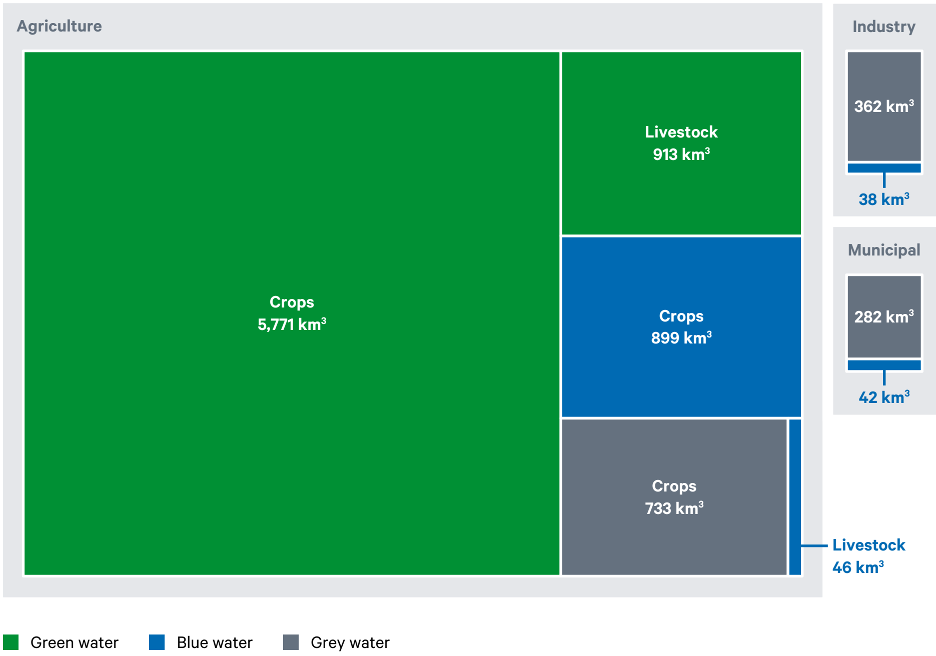


Source: Calculated from multiple data sources (as referenced in body text).

25 Global Commission on the Economics of Water (2024), *Policy Brief: Agricultural Trade and the Economics of Water*, https://watercommission.org/publication/policy-brief-agricultural-trade-and-the-economics-of-water.

From a consumption – or footprint – perspective that excludes withdrawn return flows, agriculture accounts for 92 per cent of all blue water consumed by humanity, with 4 per cent going to animal pastures and animal-raising and 88 per cent going to crop production (including animal feedstocks). Pollution from crop agriculture accounts for 53 per cent of humanity's grey water footprint (Figure 2).[26]

Figure 2. Humanity's global water footprint by sector and water type



Source: Calculated from Hoekstra, Y. and Mekonnen, M. (2012), 'The Water Footprint of Humanity', *Proceedings of the National Academy of Sciences of the United States of America*, 109 (9), pp. 3232–27, https://doi.org/10.1073/pnas.1109936109.

Critical aspects of water use in the food and agriculture sector

Intensity of water use

The volumes of water used in producing and supplying food, and the sustainability impacts of these uses, vary enormously by agricultural commodity and geography of production. While green water access is an important determinant of effective water availability and needs to be accounted for in analysis of virtual water use,[27] much of the global product-level data on water use covers blue water only. Moreover, there are wide variations in the volumes (let alone sustainability) of blue water use

26 Calculated from Hoekstra, Y. and Mekonnen, M. (2012), 'The Water Footprint of Humanity', *Proceedings of the National Academy of Sciences of the United States of America*, 109 (9), pp. 3232–27, https://doi.org/10.1073/pnas.1109936109.
27 Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.

associated with production of different food goods, or with production of similar goods in different places.

A meta-analysis of studies of global food production systems[28] found that the mean volume of water used in the food supply chain (whether considering the mass, energy or protein content of the food) often differed significantly from the median volume of water used for any given product; the meta-analysis also found frequent substantial differences in the volumes of water used between one product and another. For example, over 5,500 litres of water are used to produce a kilogramme of cheese on a mean average basis, but the median volume required is far lower: a little over 1,500 litres. This suggests the data are significantly skewed by the inclusion of water-intensive supply chains (with the effects mostly due to water-intensive agricultural production). It also suggests that considerable efficiencies can be gained by concentrating food production in places where producers use less water, or by switching to more water-efficient production methods. Globally, on both a mean and median basis, the most water-intensive foods are meats (especially beef, pork and lamb), farmed fish and crustaceans, nuts, rice and cheese; cultivation of many fruits and vegetables requires significantly smaller volumes of water (see Figure 3).[29]

In principle, this means significant water savings are potentially achievable both through supply-side measures (such as changing production practices and locations) and demand-side reforms (such as dietary change). However, volumetric comparisons of water use do not tell the whole story. They are insufficient, on their own, to determine the likely impacts of food and agricultural production on a given country or region's water security. Assessments also need to factor in the relative abundance or scarcity of water in different locations: using a greater volume of water from a water-abundant region may cause less water stress than using a smaller volume from a more water-stressed area. Robust water governance that accounts for the drivers of demand pressures is therefore necessary if supply-side investments or technologies are to be effective in increasing the sustainability of water use.[30]

The argument for a holistic approach – combining supply- and demand-side measures – to transforming food systems underpins the first of five 'missions' articulated by the Global Commission on the Economics of Water in a report published in 2024.[31] The commission – an independent body established in 2022 with a two-year mandate, convened and facilitated by the government of the Netherlands and the OECD respectively – calls for humanity to reduce its collective dependence on water-intensive foods. The commission emphasizes the need for increased water productivity in farming, and for widespread adoption of regenerative agricultural systems to preserve soil health. The commission's report also champions dietary change, calling for the share of plant-based foods in people's protein consumption to rise to 30 per cent by 2050.[32]

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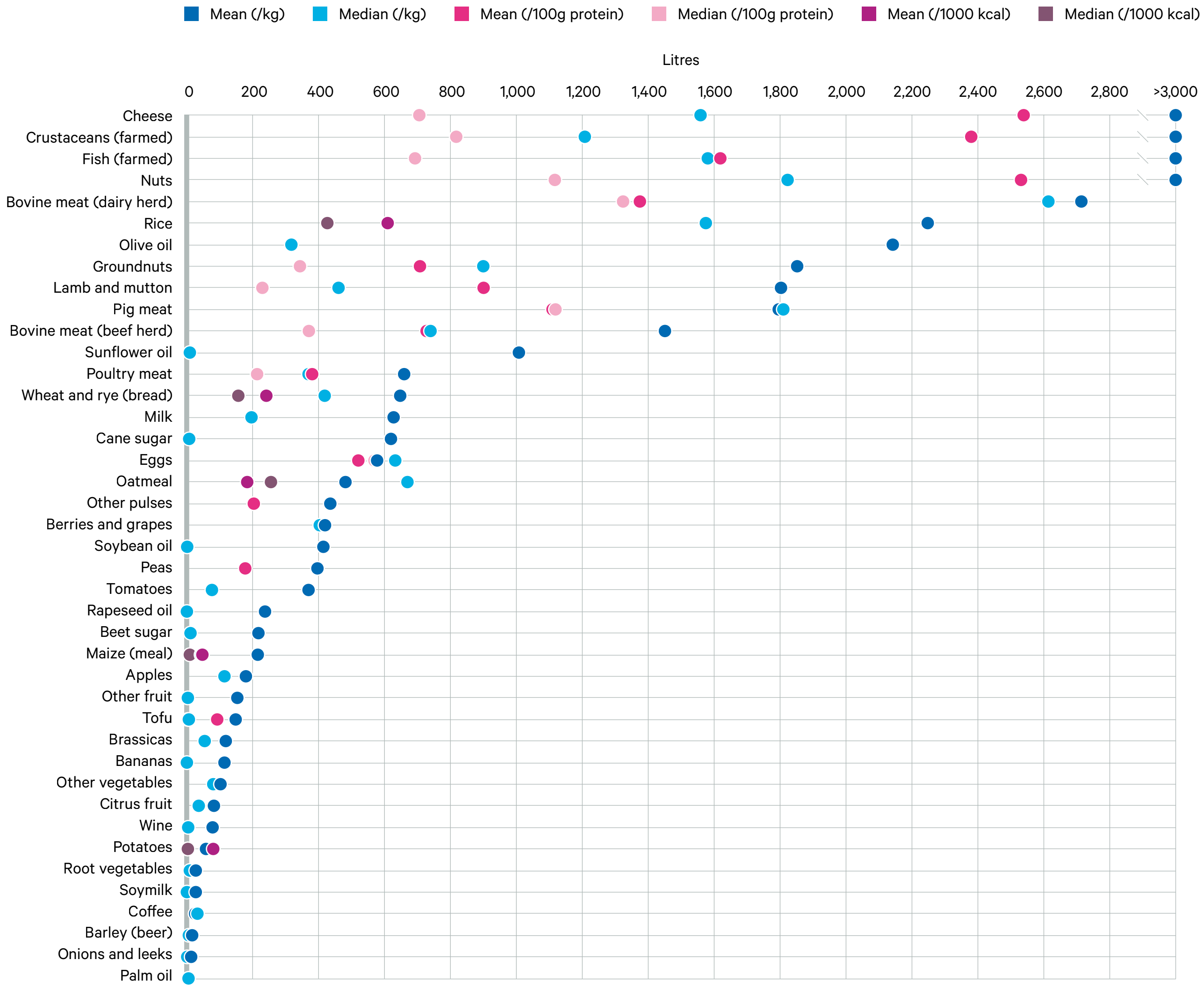
28 Poore and Nemecek (2018), 'Reducing Food's Environmental Impacts through Producers and Consumers'.
29 Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.
30 Pérez-Blanco, C. et al. (2021), 'Agricultural water saving through technologies: a zombie idea', *Environmental Research Letters*, 16 (11), 114032, https://doi.org/10.1088/1748-9326/ac2fe0.
31 The five missions are: (1) to 'launch a new revolution in food systems'; (2) to 'conserve and restore natural habitats critical to protect green water'; (3) to 'establish a circular water economy'; (4) to 'enable a clean-energy and AI-rich era with much lower water intensity'; and (5) to 'ensure that no child dies from unsafe water by 2030'. Global Commission on the Economics of Water (2024), *The Economics of Water*.
32 Ibid.

Figure 3. Virtual water requirements by food type, in litres



Note: Chart capped at 3,000 litres.
Source: Calculated from Poore, J. and Nemecek, T. (2018), 'Reducing Food's Environmental Impacts through Producers and Consumers', *Science*, 360 (6392), pp. 987–92, www.science.org/doi/10.1126/science.aaq0216.

Impacts of water use

Agriculture is typically the most water-intensive stage of a food supply chain, though food processing also often uses significant volumes of water. These impacts are visible in data from CDP, a non-profit organization that runs an environmental reporting system: accounting for both blue and grey water, and factoring in other stages in the value chain beyond production, CDP's Water Watch impact index qualitatively assesses the global environmental impacts of freshwater use by farming and food and beverage processing, among other industrial activities (Table 1).[33] We can see in the table that virtually all categories of agriculture and food production have impacts assessed as 'critical' or 'very high', with the impacts of water withdrawals and water pollution being most severe in the farming (as opposed to the processing and consumption) stages of the supply chain.

33 CDP (2023), 'Water Watch', https://www.cdp.net/en/disclose/question-bank/water-security/water-watch (accessed 1 Sep. 2025).

Table 1. Freshwater impacts from farming and food processing activities

Activity group	Activity	Overall water impact	Water impact class	Direct: High volume withdrawal/ consumption dependence	Direct: Water pollution/ degradation potential	Supply chain: High volume withdrawal/ consumption dependence	Supply chain: Water pollution/ degradation potential	Use of product/ service: High volume withdrawal/ consumption dependence	Use of product/ service: Water pollution/ degradation potential
Crop farming	Cotton farming	18	Critical	3	3	3	3	3	3
	Cocoa bean farming	16	Critical	3	3	3	3	2	2
	Fruit farming	16	Critical	3	3	3	3	2	2
	Grain and corn farming	16	Critical	3	3	3	3	2	2
	Other crop farming	16	Critical	3	3	3	3	2	2
	Palm oil farming	16	Critical	3	3	3	3	2	2
	Rice farming	16	Critical	3	3	3	3	2	2
	Soybean farming	16	Critical	3	3	3	3	2	2
	Sugar cane farming	16	Critical	3	3	3	3	2	2
	Vegetable farming	16	Critical	3	3	3	3	2	2
	Other oilseed farming	15	Critical	3	3	2	3	2	2
	Biofuel supply	12	Very high	2	3	3	3	0	1
Fish and animal farming	Cattle farming	16	Critical	2	3	3	3	2	3
	Poultry and hog farming	16	Critical	2	3	3	3	2	3
	Aquaculture	15	Critical	2	3	3	3	2	2
	Other animal farming and processing	13	Very high	2	3	3	3	1	1
	Fishing	11	Very high	1	1	2	2	2	3

Activity group	Activity	Overall water impact	Water impact class	Direct: High volume withdrawal/ consumption dependence	Direct: Water pollution/ degradation potential	Supply chain: High volume withdrawal/ consumption dependence	Supply chain: Water pollution/ degradation potential	Use of product/ service: High volume withdrawal/ consumption dependence	Use of product/ service: Water pollution/ degradation potential
Food and beverage processing	Soybean processing	15	Critical	2	2	3	3	2	3
	Palm oil processing	14	Very high	2	2	3	3	2	2
	Sugar	14	Very high	2	2	3	3	2	2
	Animal processing	13	Very high	2	3	3	3	1	1
	Dairy and egg products	13	Very high	2	3	3	3	1	1
	Oilseed processing	13	Very high	1	2	3	3	2	2
	Alcoholic beverages	12	Very high	2	2	3	3	1	1
	Chocolate confection	12	Very high	2	2	3	3	1	1
	Coffee	12	Very high	2	2	3	3	1	1
	Fruit, nut and vegetable processing	12	Very high	2	2	3	3	1	1
	Non-alcoholic beverages	12	Very high	2	2	3	3	1	1
	Non-chocolate confection	12	Very high	2	2	3	3	1	1
	Other food processing	12	Very high	2	2	3	3	1	1
	Tea	12	Very high	2	2	3	3	1	1
	Baked goods and cereals	10	High	1	1	3	3	1	1
	Grain and corn milling	10	High	1	1	3	3	1	1
	Seafood processing	10	High	2	3	1	2	1	1
Tobacco	Tobacco products	14	Very high	3	3	3	3	0	2

Source: CDP (2023), 'Water Watch', https://www.cdp.net/en/disclose/question-bank/water-security/water-watch (accessed 1 Sep. 2025).

Virtual water trade in food and agriculture

The world's vast geographic variations in soil and water resources provide a natural incentive to trade. Individual countries are motivated to trade food – and, with it, virtual water – either because they do not produce certain foods and agricultural goods themselves (and need to import them) or because they seek economic advantage in exporting goods that other countries lack or cannot produce as efficiently.

At best, such trade maximizes the redistributive potential from resource discrepancies between countries and regions, so that those with abundant natural capital can sustainably provide goods to countries and regions with lands less suited to producing particular foods, and can be appropriately remunerated for doing so. Arid countries typically use food imports as a means of circumventing local water scarcity,[34] while low-income countries' participation in food trade – both exporting and importing – typically improves the affordability of nutrients available to their own populations.[35]

But at worst, food trade can result in unsustainable exploitation and expropriation of water resources, driven by consumption that is physically dislocated from the site of impact. In such instances, it is all too easy for market participants to be unaware of, or unconcerned with, the harmful (but geographically distant) environmental and social impacts of their consumption.[36]

In today's global context of pronounced geopolitical, economic and environmental turbulence with greater multipolarity, contestation and securitization, there is a troubling risk of a new scramble for resources, in which countries with significant geopolitical heft may wield their soft (or even hard) power and economic influence to exploit other countries' natural resources, including water. Given their differences in natural, economic and political resources, countries have very uneven susceptibilities to the pressures and water scarcity issues increasingly being witnessed. Their responses, quite naturally, are likely to prioritize protecting their own national interests such as food security and critical resource supplies. As such, the resilience of food supply chains and trading relationships is increasingly a core security concern, especially for countries with significant food-import dependencies. In the UK, for example, the government's *UK Food Security Report 2024* and the 2025 food strategy for England acknowledged increasing risks from climate change and geopolitical tensions. Both documents identified the need for coordinated action to manage risks and strengthen resilience across the food system.[37]

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34 Delbourg, E. and Dinar, S. (2020), 'The globalization of virtual water flows: Explaining trade patterns of a scarce resource', *World Development*, 131, p. 104917, https://doi.org/10.1016/j.worlddev.2020.104917.
35 Traverso, S. and Schiavo, S. (2020), 'Fair trade or trade fair? International food trade and cross-border macronutrient flows', *World Development*, 132, p. 104976, https://doi.org/10.1016/j.worlddev.2020.104976.
36 King, R. et al. (2023), *The emerging global crisis of land use: How rising competition for land threatens international and environmental stability, and how the risks can be mitigated*, Report, London: Royal Institute of International Affairs, https://doi.org/10.55317/9781784135430.
37 Department for Environment, Food and Rural Affairs (Defra) (2024), *UK Food Security Report 2024*, https://www.gov.uk/government/statistics/united-kingdom-food-security-report-2024; Defra (2025), 'A UK government food strategy for England, considering the wider UK food system', policy paper, 15 July 2025, https://www.gov.uk/government/publications/a-uk-government-food-strategy-for-england/a-uk-government-food-strategy-for-england-considering-the-wider-uk-food-system.

Signifying the growing importance of beyond-military national resilience, in the summer of 2025 NATO members committed to spending up to 1.5 per cent of GDP annually by 2035, on top of core defence spending, to 'protect our critical infrastructure, defend our networks, ensure our civil preparedness and resilience, unleash innovation, and strengthen our defence industrial base'.[38] This spending will extend far beyond food security and water security, but securitization of trade is an increasingly important frame for governing virtual water flows.

Trade growth

The globalization of water resources through the international trade of food and agricultural goods has increased dramatically over the past 40 years. Virtual water trade in this sector roughly trebled in volume, to around 2,800 km^3, between 1986 and 2022. Agriculture accounted for around 65 per cent of the volume of all virtual green and blue water trade in all economic sectors in this period.[39]

The globalization of water resources through the international trade of food and agricultural goods has increased dramatically over the past 40 years. Virtual water trade in this sector roughly trebled between 1986 and 2022.

In theory, increased virtual water trade can contribute to more sustainable water use in the sector by concentrating production in areas of relative abundance and more favourable farming conditions, and by exporting food and agriculture products to more water-stressed areas where production is unsustainable. International trade can also promote global water savings, especially when areas of higher water productivity export to areas of lower water productivity (i.e. where the amount produced per unit of water is less). Every year around 240–450 km^3 of water (equivalent to 96–180 million Olympic-sized swimming pools) are saved globally due to international trade.[40] Much of these efficiency savings are due to trade in cereal crops, oil crops and livestock products.

Of course, increased water savings at an aggregate level may still translate into more or less sustainable water uses in different places, depending on how the volumetric efficiency of global water use impacts water stress in particular basins. Critically, where the value and scarcity of water are not reflected in its pricing, trade can exacerbate water depletion.[41]

As the impacts of climate change intensify and geographic imbalances in water availability increase, there could be significant disruptions to global trade in virtual water. Modelling by the Global Commission on the Economics of Water suggests

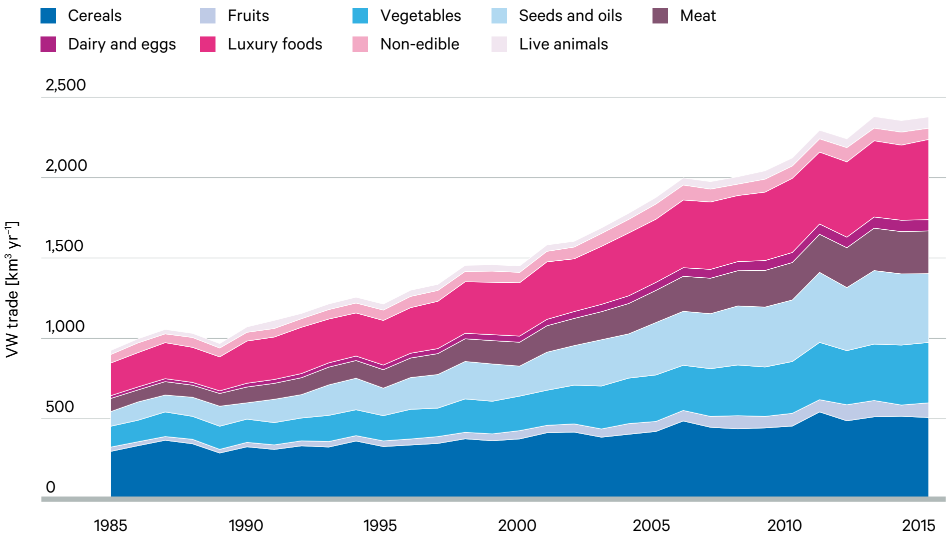
38 NATO (2025), 'The Hague Summit Declaration', 25 June 2025, https://www.nato.int/en/about-us/official-texts-and-resources/official-texts/2025/06/25/the-hague-summit-declaration.
39 Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.
40 Ibid.
41 Global Commission on the Economics of Water (2024), *The Economics of Water.*

there could be a global decline in the volume of agricultural commodities traded if prices for water-intensive goods rise.[42] Conversely, other analysts and observers expect that the water savings achieved through trade will increase, primarily due to reconfigurations in global wheat trade, with exports from water-efficient regions to less water-efficient regions expected to rise substantially.[43] Under either circumstance, nonetheless, it is possible to envisage significant impacts on countries' economic resilience and people's livelihoods and food security, requiring potentially important and wide-ranging adaptations.

Many other factors beyond water availability and its impact on sourcing decisions contribute to dietary demand pressures. Differences in social, economic and environmental conditions determine countries' comparative advantages in food and agricultural production, as well as the degree to which each country can pursue and realize these advantages. Consequently, in some cases food and agricultural trade can contribute to unsustainable demand and inefficient or inequitable water footprints.

Virtual water trade increased in all categories of agricultural commodities over the period 1986–2016, with the smallest increase seen in the non-edible goods category (32 per cent) and the largest in the seeds/oils category (where virtual water trade more than trebled) (Figure 4). The relative contribution of each category has also changed over time: most noticeably, cereals' share of virtual water trade among agricultural commodities decreased, falling from 32 per cent in 1986 to 21 per cent in 2016.[44] By the end of that period, over half of agricultural virtual water trade occurred in the trade of livestock products, oil crops and cocoa.

Figure 4. Growth in agricultural virtual water trade, 1986–2016

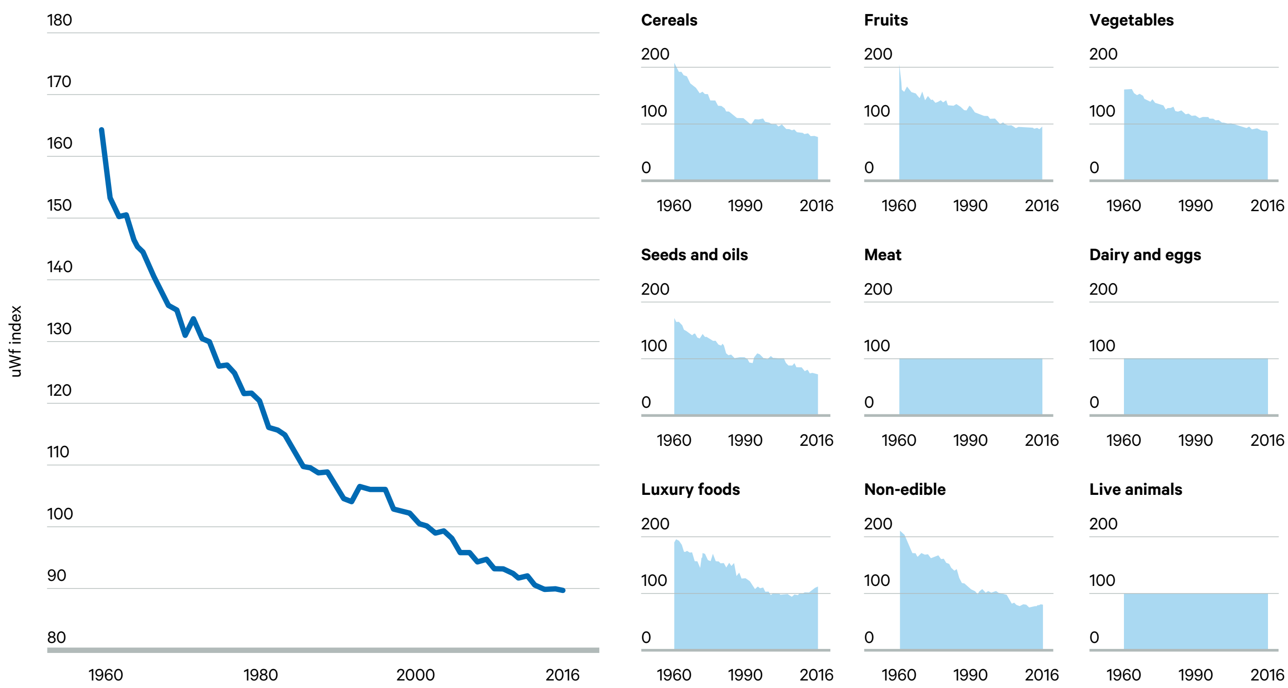


Source: Tamea, S., Tuninetti, M., Soligno, I. and Laio, F. (2021), 'Virtual Water Trade and Water Footprint of Agricultural Goods: The 1961–2016 CWASI Database', *Earth System Science Data*, 13 (5), pp. 2025–51, https://doi.org/10.5194/essd-13-2025-2021.

42 Ibid.
43 Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.
44 Tamea, S., Tuninetti, M., Soligno, I. and Laio, F. (2021), 'Virtual Water Trade and Water Footprint of Agricultural Goods: The 1961–2016 CWASI Database', *Earth System Science Data*, 13 (5), pp. 2025–51, https://doi.org/10.5194/essd-13-2025-2021.

Two main factors are, one way or another, affecting the volumes of virtual water trade in the food and agriculture sector. The first is that international trade in food products and agricultural commodities has increased in absolute terms, driven by global population and income growth and by shifts in dietary preferences. The second is that the volumes of water being used per unit weight of traded goods – a measure known as the unit water footprint (uWF) – are changing. The relative contribution of these two drivers varies per product, but on the whole the uWF has fallen across all commodity categories since 1961 – most noticeably for cereals and oils, and less so for fruits and vegetables (Figure 5).[45] Luxury foods were the only category to have seen noticeable global *increases* in the uWF (more water consumption per tonne of production) in the decade up to 2016. Demand for coffee and cocoa beans has been the main factor in this rise, though the uWF for luxury foods has still declined notably relative to 1961. Due to data limitations, it is not possible determine how the uWF for animal-based products has changed over time; hence the flat graphs for three categories – meat, dairy and eggs, live animals – in Figure 5. All that can be said with confidence is that the significant growth of virtual water trade in animal-based products, increasing to 2.5 times the 1986 volume by 2022,[46] reflects increased quantities of these products being traded as global incomes and demand for animal foods have risen.

Figure 5. Unit water footprints (uWFs) for agricultural commodities, 1961–2016



Source: Tamea, S., Tuninetti, M., Soligno, I. and Laio, F. (2021), 'Virtual Water Trade and Water Footprint of Agricultural Goods: The 1961–2016 CWASI Database', *Earth System Science Data*, 13 (5), pp. 2025–51, https://doi.org/10.5194/essd-13-2025-2021.

45 Ibid.
46 Calculated from Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.

Empirical studies have demonstrated that, despite its theoretical potential, virtual water trade does not lead to a more even distribution of the water content embedded in the consumption of agricultural goods across countries.[47] In reality, other factors such as capital and wages are likely to have a greater influence than water availability over where production occurs, especially as water is rarely priced properly.

In any case, these relative efficiency improvements are only part of the story and may be undermined by the fact that more efficient production can also lead to increased absolute resource demand.[48] Put another way, the easier it becomes to produce food efficiently, the more this stimulates demand. Some additional demand is driven by population growth, and by dietary changes associated with socio-economic progress. Some of these demand drivers are undeniably unsustainable. Further, demand- and climate-driven water stressors in key production areas continue to erode the resilience of food supply, even as global production becomes more water-efficient.

Trade distributions

In addition to the absolute volumes, the geographical distribution of agricultural virtual water trade has changed significantly since 1986. Generally, Asian countries, especially China, India and Indonesia, have become much more embedded in global supply chains, whereas African countries' trade connections have remained weaker. In 1986, the top five importers, accounting for 37 per cent of the global virtual water trade associated with agricultural products, were Japan, the US, the former USSR, the Netherlands and China. By 2022, China, the US, Germany, the Netherlands and India made up the top five, accounting for 34 per cent of imports of agricultural virtual water. Over this period, Australia, Argentina and Brazil remained net exporters of agricultural virtual water, while China, Japan, Italy, the UK and Egypt were consistently net importers. Pakistan, the Philippines, South Africa and Turkey shifted from being net exporters to net importers of agricultural virtual water.[49]

China's growth as a major agricultural importer has been significant for virtual water trade: by 2022, the country accounted for 40 per cent of global virtual water imports for soybeans, 16 per cent for livestock products and 10 per cent for oil palm. Illustrating how virtual water trade can result in consumption changes that globally redistribute environmental benefits and harms, growth in Chinese imports of soybeans (especially from the US and Brazil) and oil palm (especially from Indonesia and Malaysia) since the start of the century has resulted in water conservation in China yet deforestation in Indonesia and the Brazilian Amazon.[50]

47 Carleton, T., Crews, L. and Nath, I. (2024), 'Is the World Running Out of Fresh Water?', AEA Papers and Proceedings, 114, pp. 31–35, https://doi.org/10.1257/pandp.20241008; Afkhami, M. et al. (2022), 'Virtual water and the inequality in water content of consumption', *Environment and Development Economics*, 27(5), pp. 470–90. https://doi.org/10.1017/S1355770X21000401.
48 Grafton, R. et al. (2018), 'The Paradox of Irrigation Efficiency', *Science*, 361 (6404), pp. 748–50, https://doi.org/10.1126/science.aat9314; Pérez-Blanco et al. (2021), 'Agricultural water saving through technologies'.
49 Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.
50 Ibid.

Trade impacts (blue water)

To understand food and agriculture's real impacts on surface and groundwater resources, measures of sustainability are needed, not just volume measures that ignore local availability of renewable water sources.

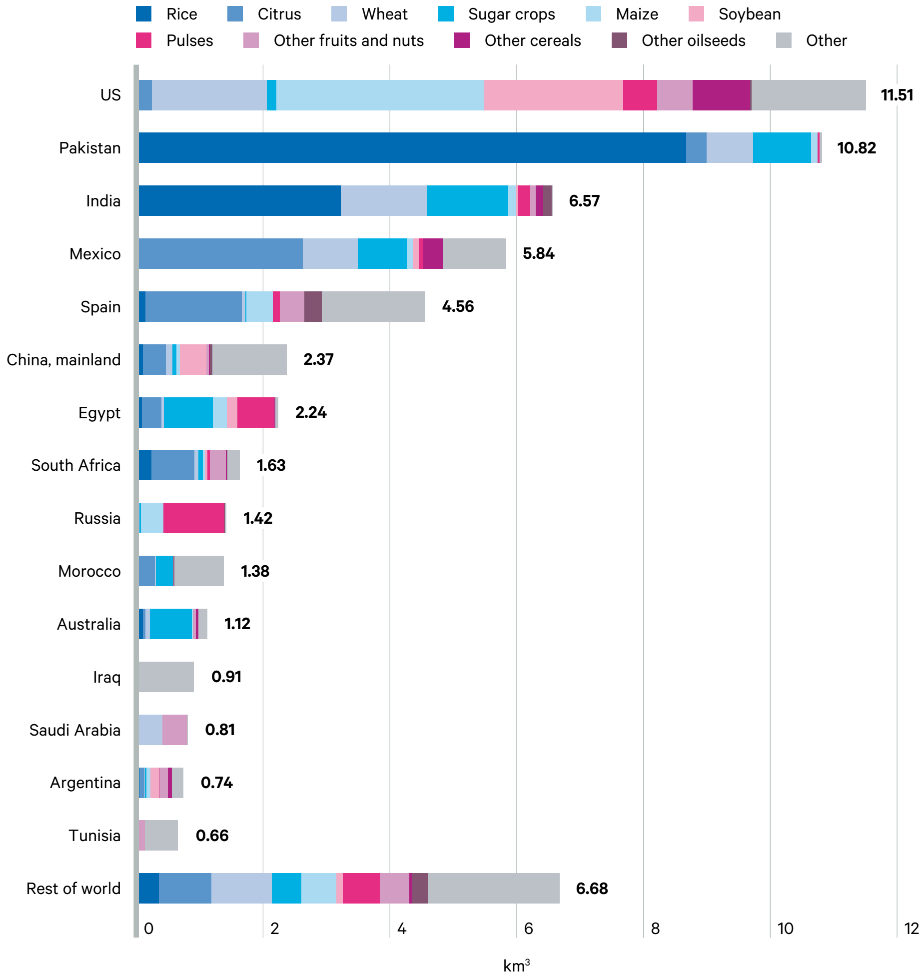
Cotton dominates unsustainable blue water trade among crops, and accounted for one-third of the global total in 2015.[51] (A forthcoming accompanying paper in this series will examine the water footprints of the textiles trade in detail.) The analysis here focuses on the embedded blue water content of crop trade only, due to data limitations for livestock.[52] With cotton excluded, rice, other annual crops, citrus fruits, wheat, maize, sugar cane, soybeans and pulses account for over 90 per cent of the remainder of unsustainable blue water trade. Cocoa, a water-intensive crop which accounts for 11 per cent of embodied green and blue water trade flows,[53] is largely rainfed, with a water footprint overwhelmingly comprised of green water consumption.[54] Thus, while it can contribute to changes in the hydrological cycle – especially where grown at scale as a commodity crop on lands cleared from rainforests – cocoa does not have a significant unsustainable blue water footprint.

Growth in Chinese imports of soybeans and oil palm since the start of the century has resulted in water conservation in China yet deforestation in Indonesia and the Brazilian Amazon.

Geographically (again excluding cotton trade), the US (19 per cent), Pakistan (18 per cent), India (11 per cent), Mexico (10 per cent) and Spain (8 per cent) dominated unsustainable blue water crop exports in 2015 (see Figures 6 and 7). In contrast, the US (10 per cent) and China (7 per cent) accounted for the largest import volumes in the same year (see Figures 8 and 9). In general, the supply of crops produced with unsustainable blue water sources is more concentrated than the demand for such crops, highlighting the exposure to water risks of relatively few water-stressed 'breadbasket' regions.

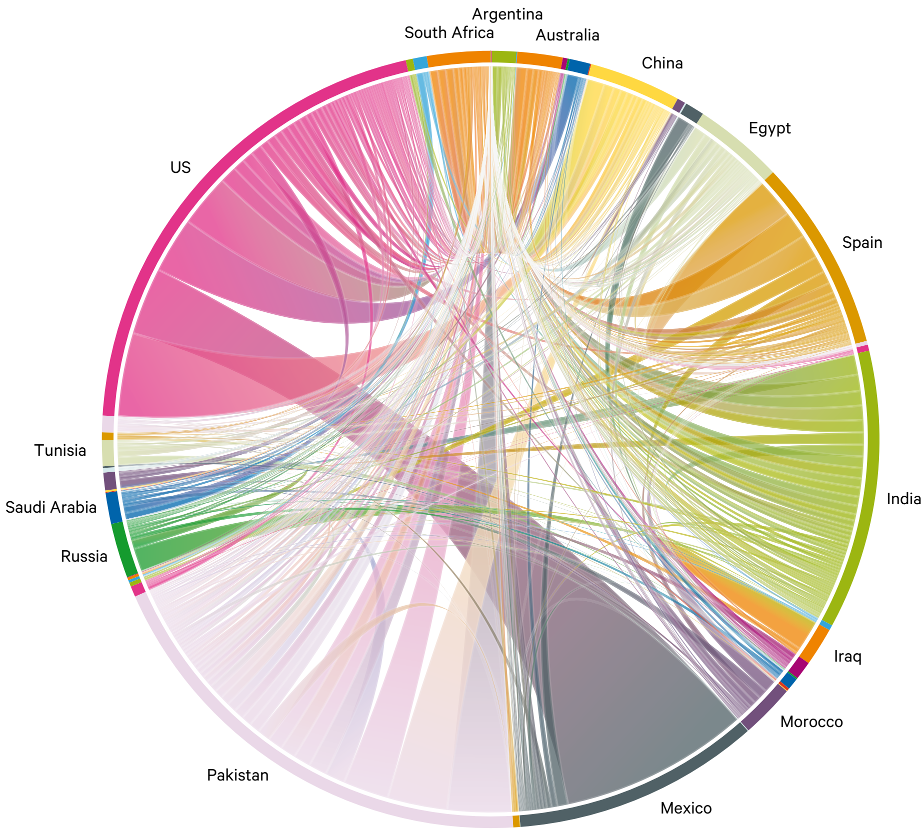
51 Rosa et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade'.
52 No analysis is presented here on the sustainability of green water use, as the issues are somewhat different. Rainfed agriculture's reliance on green water is unsustainable where it leaves insufficient water for nature or 'environmental flow requirements', or impinges on biodiversity through, for example, agricultural expansion.
53 Calculated from Mekonnen et al. (2024), 'Trends and Environmental Impacts of Virtual Water Trade'.
54 Mekonnen, M. M. and Hoekstra, A. Y. (2011), 'The green, blue and grey water footprint of crops and derived crop products', *Hydrology and Earth System Sciences*, 15, pp. 1577–1600, https://doi.org/10.5194/hess-15-1577-2011.

Figure 6. Top 15 exporters of unsustainable blue water in crops, 2015 (excluding cotton)



Source: Calculated from Rosa, L. et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade', *Environmental Research Letters*, 14 (11), 114001, https://doi.org/10.1088/1748-9326/ab4bfc.

Figure 7. Global exports of unsustainable blue water in crops, 2015 (excluding cotton)



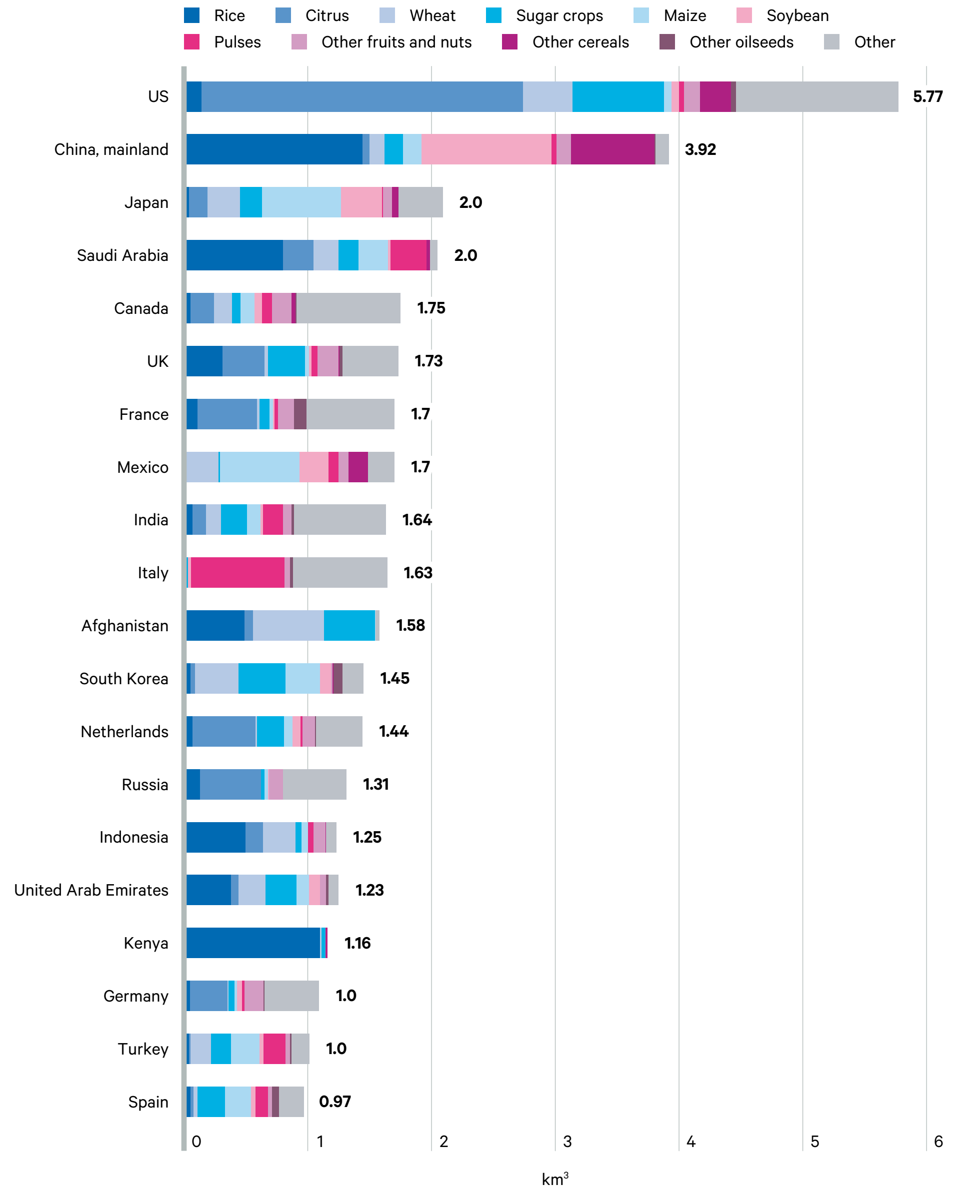
Note: The circumference of the circle represents the volume of unsustainable blue water embedded in global crop trade (excluding cotton). The size of each country's arc is proportional to its export volume. The chord between two countries represents the bidirectional trade between them; the width of the chord at the end where it meets an exporting country's arc represents the share of the volume exported from that country to the other.

Source: Calculated from Rosa, L. et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade', *Environmental Research Letters*, 14 (11), 114001, https://doi.org/10.1088/1748-9326/ab4bfc.

The major exporters and importers of crops associated with unsustainable blue water use represent a wide spectrum of economic development – producers are not all developing countries, nor are consumers all advanced economies. Nor is the direction of trade all one-way in terms of where Global North or Global South countries fit into the supply chain: unsustainable virtual water flows occur on a North–South, South–South, South–North and North–North basis.[55] As for specific bilateral relationships, the largest volumes of unsustainable water are embodied in crop exports from Mexico to the US (over twice the volume of the next largest trade), from the US to China, from the US to Mexico, from Pakistan to Afghanistan, and from Pakistan to China (see Annex 1, Table A2).

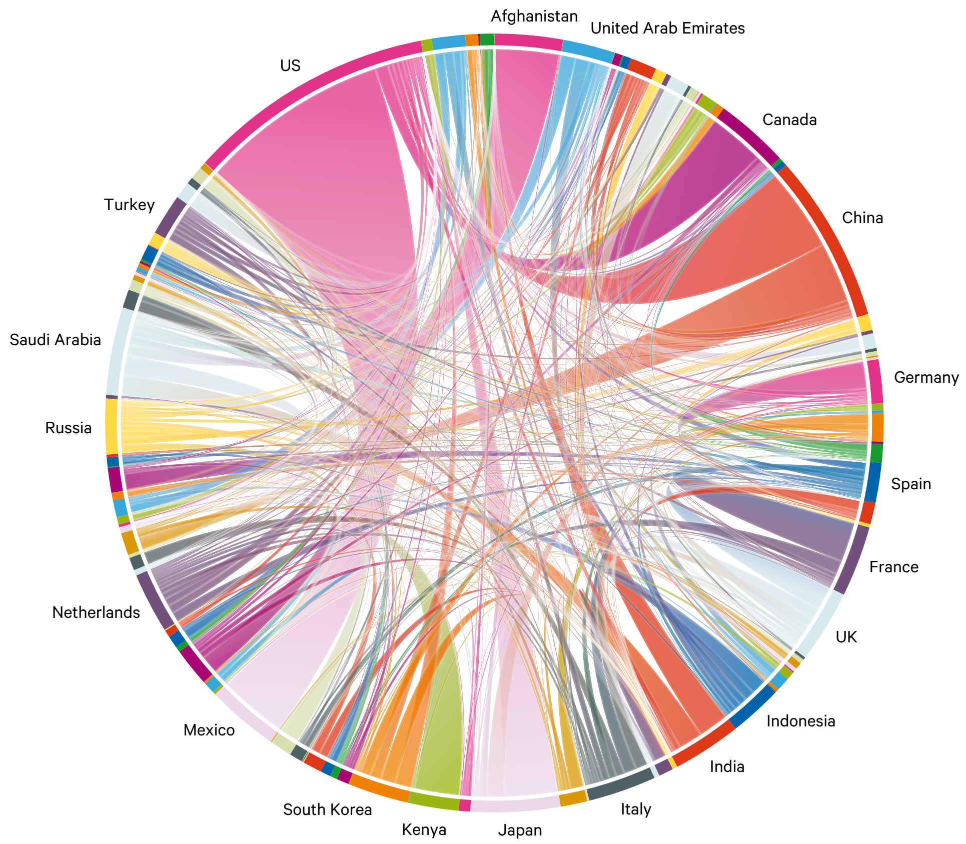
55 Calculated from Rosa et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade'.

Figure 8. Top 20 importers of unsustainable blue water in crops, 2015 (excluding cotton)



Source: Calculated from Rosa, L. et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade', *Environmental Research Letters*, 14 (11), 114001, https://doi.org/10.1088/1748-9326/ab4bfc.

Figure 9. Global imports of unsustainable blue water in crops, 2015 (excluding cotton)



Note: The circumference of the circle represents the volume of unsustainable blue water in global crop trade (excluding cotton). The size of each country's arc is proportional to its import volume. The chord between two countries represents the bidirectional trade between them; the width of the chord at the end where it meets an importing country's arc represents the share of the volume imported by that country from the other.

Source: Calculated from Rosa, L. et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade', *Environmental Research Letters*, 14 (11), 114001, https://doi.org/10.1088/1748-9326/ab4bfc.

Water availability challenges

Globally, both chronic and acute lack of water availability pose significant challenges to agricultural production. Around 11 per cent of rainfed croplands (this share covering an area approximately equivalent to the size of Chad or Niger) and 14 per cent of pasturelands (a share covering roughly twice the size of India) face severe recurring droughts. Of the world's total area of irrigated croplands, over 60 per cent – covering an area similar in size to Iran – faces high or very high water stress.[56]

56 The area of irrigated croplands that are highly or very highly water stressed is 171 million ha. Food and Agriculture Organization of the UN (FAO) (2020), *The State of Food and Agriculture 2020: Overcoming water challenges in agriculture*, https://doi.org/10.4060/cb1447en; country equivalents sourced from FAO (2025), 'FAOSTAT' https://www.fao.org/faostat/en (accessed 1 Sep. 2025).

While this challenges food security on a global aggregate basis, it also has direct implications for local communities living in the most affected regions: around one in six people on the planet (1.2 billion people) live in severely water-constrained agricultural areas. In Central Asia, Western Asia and Northern Africa (UN geographical definitions), around 20 per cent of the population lives under such threats, whereas in regions beyond Asia and Northern Africa less than 5 per cent of the population faces these direct risks.[57]

Climate change is expected to increase water shortages and water scarcity, with negative effects on agricultural production, particularly in low-latitude and tropical regions. Nonetheless, the location and magnitude of these impacts over the remainder of the century are still somewhat uncertain,[58] and climate models do not provide a reliable picture of likely disruptions to rainfall. As illustrated in Annex 2, the effects of water shortages are not purely a function of the incidence of climatic and weather events, but also reflect the degree of exposure and vulnerability of people and agricultural assets to droughts, as well as their more general vulnerability and readiness to adapt to all negative effects of climate change.

Given that approximately 80 per cent of total cropland is under rainfed production, the majority of the world's farmers have limited ability to adapt to weather variability. As a result, by and large they cannot influence the volumes and timings of water availability for plant growth. This is particularly a problem for small-scale farmers engaging in low-input rainfed production, who often have limited capacity to invest in water management techniques such as rainwater harvesting or water conservation.[59] However, with improved agricultural 'extension' services – defined as services to train, educate and advise farmers – some basic methods of conserving green water can be implemented at little expense.[60] For example, digging deeper furrows and improving tilling techniques can maintain soil moisture, boost infiltration rates and reduce surface run-off from fields.

As the climate changes, it is not only the quantity of water available to agriculture that will be affected but the water requirements of agriculture itself. Under hotter conditions, more soil moisture evaporates and plants transpire more rapidly as they photosynthesize. If conditions are too dry, then plants will conserve their water use, but this often results in failed or stunted growth and death. Although rising atmospheric carbon dioxide levels, in principle, can accelerate plant growth, increased water stress in the future is likely to negate any such 'CO_2 fertilization' benefits.[61] This is why virtual water trade could become an even more important mechanism over the coming decades for conserving and redistributing food production to areas with higher availability of sustainable water. Whether this actually happens or not will, however, depend predominantly on other factors also influencing production decisions, such as how demand evolves and the policy choices countries make around economic development.

57 FAO (2020), *The State of Food and Agriculture 2020*.
58 Ibid.
59 Ibid.
60 The Transforming Investment in Africa's Rainfed Agriculture (TIARA) project is a good example of an initiative promoting such approaches. See Stockholm International Water Institute (SIWI) (undated), 'Transforming Investment in Africa's Rainfed Agriculture (TIARA)', https://siwi.org/transforming-investment-in-africas-rainfed-agriculture-tiara.
61 Dunne, D. (2019), 'Rising water stress could counteract 'global greening', study says', Carbon Brief, 14 August 2019, https://www.carbonbrief.org/rising-water-stress-could-counteract-global-green-study-says.

Country case studies

Morocco

Morocco's climate is characterized by irregular rainfall and frequent multi-year droughts. Significant geographical variation means that rainfed agriculture is viable in the northwest, but that the southeast is almost entirely dependent on irrigation, with over 80 per cent of the country's total irrigation being unsustainable (see Annex 1, Table A3). Around half of Morocco's water resources are in an area occupying only 7 per cent of the country. Over the last three decades, increasing pressures on water supplies as a result of population growth, urbanization and changing consumption patterns have resulted in Morocco having to take unconventional approaches to sourcing freshwater. These approaches have included sewage treatment, seawater desalinization and demineralization of brackish water.[62]

Agriculture is responsible for nearly 90 per cent of the country's water withdrawals, and irrigated agriculture in Morocco is predominantly export-oriented. Exports fulfil an important role in the economy, with agriculture accounting for over a fifth of export revenue. Nonetheless, Morocco remains a net importer of virtual water, using international trade to supplement domestic water availability in supporting food security, primarily through cereal imports – mainly from Europe and Latin America.[63] However, these virtual water imports have been declining, and the volume of virtual water exports has been increasing under the government's 2009 export-oriented agricultural policy.[64] A large share of the country's food and agricultural exports consists of horticultural produce for European markets.[65] High-value horticultural produce (such as citrus fruits, stone fruits and vegetables) destined for export are often much more dependent on irrigation, and more blue water-intensive, than lower-value cereal imports, so from the perspective of the country's virtual water balance, Morocco's current approach to agricultural policy and food security is increasingly problematic.

This illustrates how national policy can drive unsustainable water use that – despite having a domestic economic rationale – may be at odds with sustainable use of water and land resources, both for Morocco itself and for the global common good. Put another way, the water use associated with Morocco's horticultural exports, in addition to stressing Morocco's own natural resources, does not allow for water and land to be used most efficiently for food and agricultural production on an aggregate global basis.[66] Morocco provides an example of how a country's trade policies and domestic agricultural policies need to be joined up, so that one set of policies complements the other, to maximize the resource-optimizing potential from virtual water trade.

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62 Boudhar, S. and Boudhar, A. (2025), 'Water scarcity and the agricultural trade structure in Morocco: A quantification of virtual water flows in Morocco's foreign trade of agricultural products', *Research Square*, Preprint (Version 1), 24 February 2025, https://doi.org/10.21203/rs.3.rs-6080363/v1.
63 Chatham House (2025), 'resourcetrade.earth', https://resourcetrade.earth/?year=2022&importer=504&category=1&units=weight&autozoom=1 (accessed 29 Jul. 2025).
64 Boudhar and Boudhar (2025), 'Water scarcity and the agricultural trade structure in Morocco'.
65 Chatham House (2025), 'resourcetrade.earth', https://resourcetrade.earth/?year=2022&importer=504&category=1&units=weight&autozoom=1 (accessed 29 Jul. 2025).
66 King et al. (2023), *The emerging global crisis of land use.*

Pakistan

Pakistan is one of the world's most water-stressed countries, and by some measures is more at risk from climate-related extreme weather than any other country.[67] In 2022, 10 per cent of Pakistan was submerged by floods, yet the fertile alluvial plains of the Indus Basin, on which most of Pakistan's agriculture occurs, typically receive little rainfall, and the expansion of agriculture has outstripped the availability of water.[68]

Pakistan is one of the world's most water-stressed countries, and by some measures is more at risk from climate-related extreme weather than any other country.

Over three-quarters of Pakistan's renewable water resources come from beyond its borders – with a large proportion dependent on flows from neighbouring India, a political rival of Pakistan. Cultivation of water-intensive crops such as rice and sugar cane (as well as wheat), coupled with unsustainable groundwater extraction that depletes aquifers and degrades soil quality, is causing Pakistan's water resources to dry up. This threatens food production, millions of farmers' livelihoods, and the food security of many millions more people. In other parts of the country, inefficient irrigation often results in water seepage, causing waterlogging and excess soil salinity, and transforming formerly fertile fields into barren and unproductive lands.[69]

Inefficient farming means that sugar cane production in Pakistan requires 50 per cent more water than the global average to grow a given amount of cane. Moreover, as the sucrose content of Pakistani cane is low, the country must grow a further 20 per cent more sugar cane (and use 20 per cent more water) to yield the same quantity of sugar as from cane produced more efficiently elsewhere. Water-intensive refining further exacerbates these inefficiencies, with the result that a kilogramme of refined Pakistani cane sugar uses 1,750 litres of water, compared with a global mean value of a little over 600 litres per kilogramme (see Figure 3).

Pakistan's inefficient rice paddies consume two-thirds more water than is required, for example, under similar climatic conditions in Egypt, where modern irrigation methods are used (though irrigated rice production in water-scarce areas of Egypt presents its own challenges). Nonetheless, Pakistan exports around 4–5 million tonnes of rice each year, much of it to China and Kenya.[70]

67 Adil, L., Eckstein, D. Kunzel, V. and Schafer, L. (2025), *Climate Risk Index 2025*, Bonn: Germanwatch, https://www.germanwatch.org/sites/default/files/2025-02/Climate%20Risk%20Index%202025.pdf.
68 Shah, S. (2025), 'Climate Change Is Straining Pakistan's Water. Tensions with India Could Make It Worse', *Time*, 9 May 2025, time.com/7284470/india-pakistan-water-supply-climate-change.
69 Leghari, M. (2025), 'Pakistan's Water Crisis: The Cost of Sugarcane and Rice', *Business Recorder,* 15 April 2025, www.brecorder.com/news/40357614/pakistans-water-crisis-the-cost-of-sugarcane-and-rice.
70 Chatham House (2025), 'resourcetrade.earth', https://resourcetrade.earth/?year=2022&exporter=586&category=49&units=weight&autozoom=1 (accessed 29 Jul. 2025).

Partly as a result of this trade, Pakistan's annual virtual water exports amount to around 10 km^3, equivalent to the volume of water used by Karachi's more than 20 million people in a year and a half.[71]

This case study highlights the importance of investing in efficient farming methods to reduce the water footprint of production and reduce pressure on local water resources. Trade relationships can help with this by directing investment into improvements in the relevant areas. However, this needs to be matched with national water management and economic policy, so that these water footprint savings are used to reduce water stress, not just to expand production.

Future challenges

Much of the growth in agricultural supply and demand, and therefore in the associated water footprints, between now and the middle of this century is expected to occur in the Global South. On the demand side, the OECD and Food and Agriculture Organization of the UN (FAO) jointly project that global consumption of agricultural and fisheries products will grow by 13 per cent (at constant prices) by 2034,[72] with this additional demand occurring predominantly in low- and middle-income countries.

The relative importance of China in driving global consumption of food and agricultural products is declining, while growing urban populations and rising affluence are expected to increase India and Southeast Asia's combined share of additional global demand to 31 per cent by 2033.[73] China will still be responsible for 11 per cent of additional demand over the next 10 years, but this compares with a 28 per cent share of global demand growth in the previous decade. Rising affluence and dietary shifts are expected to result in demand for feed crops for livestock growing more rapidly than direct food use in most regions of the world.[74]

On the supply side, significant expansions in irrigated areas are expected. Relative to 2010, the harvested irrigated area in 2050 is projected to increase by 12 per cent in Eastern Asia and the Pacific, 22 per cent in the Near East and North Africa, 30 per cent in Southern Asia, 35 per cent in Latin America and the Caribbean, and more than 100 per cent in sub-Saharan Africa (FAO geographical definitions).[75] Alongside improved water management in existing irrigated and rainfed areas, this has the potential to provide substantial productivity, livelihood and poverty alleviation benefits to millions of small-scale farmers. However, it must be part of a fully integrated water management strategy and a holistic biological-geographical-hydrophysical approach that ensures, as a starting point, that all hydrological and ecosystem needs for water quality and quantity are met throughout the year.[76]

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71 Leghari (2025), 'Pakistan's Water Crisis'.
72 OECD (2025), *OECD-FAO Agricultural Outlook 2025-2034*, Paris: Organization for Economic Co-operation and Development, https://www.oecd.org/en/publications/oecd-fao-agricultural-outlook-2025-2034_601276cd-en.html.
73 OECD (2024), *OECD-FAO Agricultural Outlook 2024-2033,* Paris: Organization for Economic Co-operation and Development, https://www.oecd.org/en/publications/2024/07/oecd-fao-agricultural-outlook-2024-2033_e173f332.html.
74 Ibid.
75 FAO (2020), *The State of Food and Agriculture 2020*.
76 Ibid.

Integrated approaches and policies in agricultural water resource management must, equally, be designed and implemented in inclusive ways that are responsive to gender and other social inequalities and that promote social inclusion, ensuring the benefits are accessible to everyone. If marginalized groups are excluded from conversations about design and implementation, then approaches to agricultural water resource management are more likely to fail to meet those groups' needs; poorly designed approaches could also exacerbate social and systemic inequalities, with far-reaching implications for health, resilience, prosperity, and social and political stability. For example, without sufficient safeguards, the practice of night irrigation can pose safety threats to vulnerable groups required to be out in the fields during darkness; if these risks are not addressed, this can limit participation and ultimately lower productivity.[77]

Better water management can improve the sustainability of water use in the food and agriculture sector, even if supply-side practices alone are unlikely to be sufficient to achieve sustainability. One study suggests that improved water management and sustainably expanded irrigation could increase global caloric output by over 40 per cent without significant detrimental impacts on ecosystems and other economic sectors.[78] Another suggests that expanding irrigation on up to a quarter of global croplands – where institutional and economic capacity rather than hydrology is limiting expansion – could feed an additional 840 million people without additional aggravation of blue water scarcity. These areas are mainly located in sub-Saharan Africa, Eastern Europe and Central Asia.[79]

Yet given that the limits of sustainable irrigation potential will remain a fundamental constraint on global agricultural productivity improvements, security of food supply will remain a serious concern. A study by Beltran-Peña et al. (2020) indicates that there will only be sufficient food production capacity to feed the global population by 2100 under the most sustainable of development scenarios examined by the authors.[80] Under the business-as-usual and middle-of-the-road-scenarios modelled in the study, global demand for food and agricultural goods will outpace water-constrained production potential. Under all three of these scenarios, most countries in Africa and the Middle East will continue to rely heavily on imports of food, and therefore virtual water, throughout the remainder of the century due to their domestic water constraints.[81]

77 Turner, C., Ji, L. and Grant, M. (2023), *Applying gender equality, disability, and social inclusion principles in agricultural water resources management*, policy brief, Bangkok: Food and Agriculture Organization Thailand, https://doi.org/10.4060/cc7592en.
78 FAO (2020), *The State of Food and Agriculture 2020*.
79 Rosa, L. et al. (2020), 'Global Agricultural Economic Water Scarcity', *Science Advances*, 6 (18), https://doi.org/10.1126/sciadv.aaz6031.
80 This scenario combines a 2°C climate change pathway (RCP 2.6) with global diets that contain small proportions of calories from animal-sourced foods (SSP1). It also assumes relatively small population changes, using the low-population variant of the UN's population projections. Although it accounts for climate change, it does not factor in the impacts of climate shocks or how sustainable irrigation potential may be constrained by climate impacts.
81 Beltran-Peña, A., Rosa, L. and D'Odorico, P. (2020), 'Global Food Self-Sufficiency in the 21st Century under Sustainable Intensification of Agriculture', *Environmental Research Letters*, 15 (9), https://doi.org/10.1088/1748-9326/ab9388.

Unknowns

Better policy requires obtaining better data and better understanding of the issues. Yet many gaps remain in data and knowledge concerning water footprints for food and agriculture, especially in relation to sustainability and broader concerns around fair water footprints (see Box 1).

For example, it can be challenging to isolate how trade in rainfed agricultural goods specifically disrupts green water flows and thus compromises environmental flow requirements[82] or erodes biodiversity. Equally, there is a paucity of data on the grey water footprint of agriculture and food products, particularly in terms of data that can be segmented by country and/or commodity or product. Although much of the water footprint for food goods is directly attributable to production processes, the full picture is complicated. Product lifecycle analyses often end at the farmgate; this precludes greater understanding of the subsequent impacts of food processing, distribution, consumption and waste streams.

There is little detailed understanding of how future changes in diets, trade patterns and environmental conditions may collectively influence the volumes and geography of water availability and use over time.

Looking forward, there is little detailed understanding of how future changes in diets, trade patterns and environmental conditions may collectively influence the volumes and geography of water availability and use over time. Forecasts of national-level baseline water stress (from irrigation, livestock and economy-wide stresses – see Annex 2) show a broadly consistent global distribution of stresses over different mid- to late-century time horizons and under different climate change scenarios, albeit worsening as global temperatures rise and as time progresses.[83] However, these scenarios assume demand for agricultural products remains largely consistent with demand today – an assumption that is increasingly being challenged by consumption growth and by observable divergences in trade relationships and environmental risks relative to previous dynamics.

Water stresses may present non-linear threats in certain geographies or in respect of certain commodities. For example, reductions in glacial melt could have substantial impacts on water availability for agricultural production in countries such as India; and a reduction in groundwater levels could – aside from reducing water availability – increase the concentration of pollutants in aquifers and increase bioaccumulations in crops (arsenic in rice, for example). At the same time, rising sea levels may increase infiltration of saline water into groundwater supplies (with the consequent costs of running desalinization plants potentially being passed on to consumers).

82 The water flows required to sustain freshwater and estuarine ecosystems.
83 World Resources Institute (2023), 'Aqueduct 4.0', https://www.wri.org/aqueduct (accessed 1 Sep. 2025).

Although the precise shape of future stressors is unknowable, we can be certain that political decisions, relationships and policies will continue to exert significant influence over the management of the food and agriculture sector's water supply, water demand and water redistribution at all levels – from the global geopolitical level down to the river basin level – in the coming years. In this context, it is especially important for policy to move beyond disparate interventions siloed in individual supply chains or government departments. What is needed, instead, are holistic and coordinated efforts that promote inclusive outcomes and find synergies between water, climate and biodiversity actions taken across government, between producer and consumer countries, and involving public sector and private sector actors (see 'Conclusion and policy options'). The outcome-orientated missions championed by the Global Commission on the Economics of Water provide one useful approach to addressing these interconnections, and to finding systemic solutions.

Given that climatic pressures and other shocks disproportionally affect vulnerable communities – and the most vulnerable people within communities – it is crucial that social inclusion considerations are at the forefront of approaches to building resilience in food and agriculture's use of water resources. If policies fail to address water security in an inclusive manner, this will undermine the resilience of communities involved in, and close to, supply chains and potentially introduce additional social and political challenges to ensuring continuity of supply. The urgency of developing inclusive policies is only increasing as population, geo-economic, geopolitical and environmental pressures mount.[84]

Food and agriculture water standards

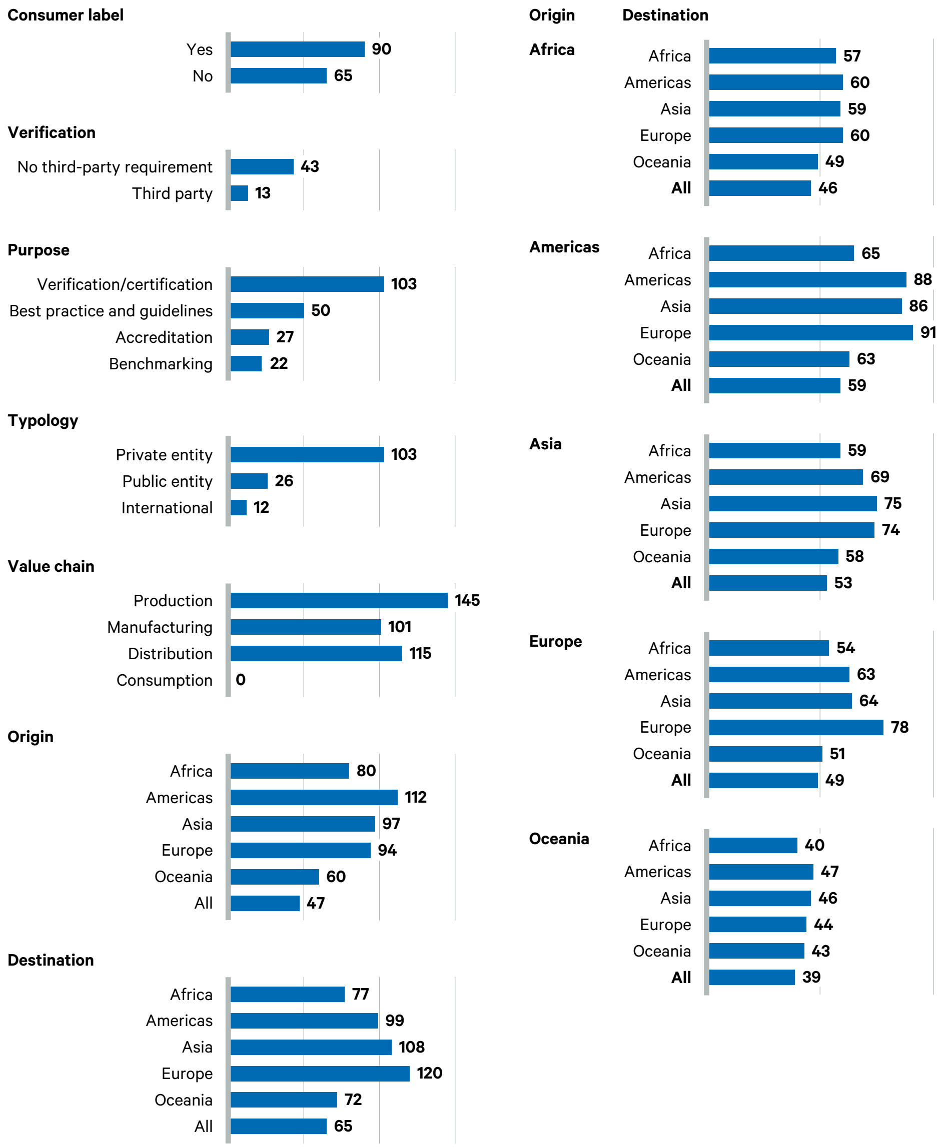
Aside from primary legislation and regulations, the use of standards can and should be leveraged to drive sustainability improvements in food and agriculture-related activities. There is a plethora of sustainability standards globally that are both applicable to food and agriculture and include measures related to water sustainability. However, the prominence of water-related issues in these standards varies greatly. The International Trade Centre (ITC), a UN agency, maintains a database of over 300 voluntary sustainability standards. Of these, 155 (43 per cent) both cover the agriculture sector, from specific crops and supply chains to more general sectoral focuses, and have at least a partial focus on water, as summarized in Figure 10.[85]

Water-related criteria may constitute major or minor requirements in these standards, many of which have been developed by private organizations for the purposes of verifying or certifying that businesses meet environmental commitments or obligations. The ITC-listed standards offer broad geographical coverage in terms of both countries of origin (i.e. producers) and destination countries (i.e. consumers). Notable standards administered by the UN or other international

84 Turner, Ji and Grant (2023), *Applying gender equality, disability, and social inclusion principles in agricultural water resources management*.
85 Of all the standards that cover agriculture, 84 per cent (155 of 185) also include water to some degree, while 53 per cent (155 of 292) of all water-including standards also include agriculture.

public bodies include the International Finance Corporation's performance standards on environmental and social sustainability, the ISO 34101 series specifying requirements for sustainable and traceable cocoa, and UNCTAD's BioTrade principles and criteria focused on terrestrial biodiversity.

Figure 10. Summary of agriculture-related voluntary sustainability standards with water criteria



Note: The summary of geographical spread is shown in the left column, while a breakdown of geographical coverage is provided in the right column. 357 standards were assessed in total. Of these 292 include water components; of these 155 relate to agriculture. The data in the figure consider these 155 agriculture-related voluntary sustainability standards with water criteria.

Source: Calculated from International Trade Centre (undated), 'Standards Map App', https://standardsmap.org/en/identify (accessed 1 Sep. 2025).

However, of the 155 standards with both agriculture and water within scope, only one – the International Water Stewardship Standard (AWS Standard) – has a predominant focus on water ahead of other sustainability concerns. This standard is the creation of the Alliance for Water Stewardship (AWS), a global membership-based collaboration whose participants represent multiple economic sectors and comprise businesses, non-governmental organizations and public sector entities. The alliance aims to drive, recognize and reward global and local leadership in credible water stewardship – encompassing the social, cultural, environmental and economic dimensions of freshwater use – through promoting adoption of the AWS Standard.[86]

The standard's compliance criteria cover areas and processes that include: water management plans; monitoring of water use and consumption; water quality; and water extraction and wastewater treatment. The AWS is code-compliant with the broader ISEAL (International Social and Environmental Accreditation and Labelling) Alliance, which is a membership organization for sustainability systems and accreditation bodies. Code-compliance status recognizes organizations adhering to the ISEAL code of good practice for sustainability systems.[87] Of the 19 code-compliant ISEAL Alliance member organizations, 10 include food-related agricultural supply chains and water issues as part of their focus (Table 2).[88]

86 International Trade Centre (2025), 'Standard profile for Alliance for Water Stewardship', Standards Map App, https://standardsmap.org/en/factsheet/120/overview (accessed 29 Jul. 2025).
87 ISEAL (undated), 'ISEAL Community Members', https://isealalliance.org/membership/iseal-community-members (accessed 29 Jul. 2025).
88 Ibid.

Table 2. ISEAL Alliance code-compliant member organizations with food and water-focused standards

Member	Food products	Geographical scope (number of countries)	Water criteria
Alliance for Water Stewardship (AWS)	Multiple, cross-sectoral	**For origin:** Africa (5), Americas (7), Asia (12), Europe (18), Oceania (2)	Extensive critical criteria requiring immediate action on: water management plans; water use record-keeping; water resource monitoring; water dependencies and scarcity; water reuse, recycling and harvesting; water extraction and irrigation; water contamination/pollution; water quality in production; water disposal/storage; wastewater treatment, etc.
Aquaculture Stewardship Council	Aquaculture products	**For origin:** Africa (54), Americas (36), Asia (48), Europe (39), Oceania (15) **For destination:** Africa (14), Americas (14), Asia (25), Europe (36), Oceania (2)	Major criteria requiring immediate action on: water use permits; water management plans; water resource monitoring; water contamination/pollution; water quality in production; wastewater treatment.
Bonsucro	Sugar	**For origin:** Americas (9), Asia (3), Oceania (1) **For destination:** Africa (53), Americas (37), Asia (50), Europe (39), Oceania (15)	Major criteria requiring immediate action on: water management plans and water contamination/pollution. Various minor criteria on: water resource monitoring; water dependencies and scarcity; water extraction and irrigation; water disposal/storage; wastewater treatment, etc.
Fair Trade USA	Bananas, cereals, cocoa, coconuts (fresh), coffee, fruits, honey, nuts, other products, palm oil, plants, rice, soy, spices, sugar, tea, vegetables (standard also covers cotton and fibres, floriculture products, flowers)	**For origin:** Africa (3), Americas (18), Asia (11), Europe (2), Oceania (2) **For destination:** Americas (2)	Major criteria requiring immediate action on: mitigation of transboundary water pollution; water contamination/pollution; water disposal/storage; wastewater treatment. Various other minor criteria requiring action within five years.
Fairtrade International	Bananas, cocoa, coffee, fruits, tea (standard also covers flowers)	**For origin:** Africa (52), Americas (31), Asia (34), Oceania (12) **For destination:** Americas (2), Asia (5), Europe (19), Oceania (2)	Major criteria requiring action on: water contamination/pollution (immediate); water quality in production, water use record-keeping, water resource monitoring (all within one year); water disposal/storage, wastewater treatment (both within three years). Various other minor criteria requiring action within three to five years.
MarinTrust	Aquaculture products, food and beverages, wild fish	**For origin:** Africa (3), Americas (6), Asia (2), Europe (8), Oceania (1) **For destination:** Africa (1), Americas (10), Asia (12), Europe (28), Oceania (2)	Major criteria requiring immediate action on water use permits.

Member	Food products	Geographical scope (number of countries)	Water criteria
Rainforest Alliance	Bananas, cereals, cocoa, coconuts (fresh), coffee, fruits, nuts, palm oil, plants, spices, tea, vegetables (standard also covers flowers)	**For origin:** Africa (23), Americas (19), Asia (13), Europe (6), Oceania (2) **For destination:** Africa (1), Americas (17), Asia (48), Europe (33), Oceania (2)	Critical criteria requiring immediate action on maintaining natural wetlands as undrained. Major criteria requiring immediate action on: water use permits; water management plans; water use record-keeping; water extraction and irrigation; water contamination/pollution; water quality in production; water disposal/storage; wastewater treatment.
Roundtable on Sustainable Palm Oil	Palm oil	**For origin:** Africa (8), Americas (19), Asia (19), Europe (29), Oceania (5) **For destination:** Africa (8), Americas (19), Asia (19), Europe (28), Oceania (5)	Major criteria requiring immediate action on: water use permits; maintaining natural wetlands as undrained; water contamination/pollution. Various other minor criteria requiring action within one year.
trustea	Tea	India	Major criteria relating to efficient water use: ensuring farming, factory processing and household water use are in accordance with central and state laws and do not negatively affect natural water bodies and sub-soil water through excessive water use or pollution.
Union for Ethical BioTrade (UEBT)	Botanical food ingredients (standard also covers non-food botanicals)	**For origin:** Africa (8), Americas (6), Asia (8), Europe (12) **For destination:** Africa (53), Americas (37), Asia (50), Europe (39), Oceania (15)	Major criteria requiring immediate action on: water use permits; water resource monitoring; water dependencies and scarcity; water contamination/pollution; water quality in production. Major criteria on wastewater treatment (action within three years). Various other minor criteria requiring action within one to three years.

Source: Compiled from International Trade Centre (undated), 'Standards Map App', https://standardsmap.org/en/identify (accessed 1 Sep. 2025).

Conclusion and policy options

Both the virtual water embedded within food and agricultural goods and the international redistribution of a significant proportion of this virtual water through global trade are enormously consequential for global water security – accounting for larger volumes of water consumption than any other sector. Due to the growth in international value chains and the globalization of diets, virtual water trade has assumed growing importance over the past 60 years. And, as climate change-related pressures mount in the coming years and decades, trade will continue to be a vital mechanism for supporting globally efficient and sustainable water use by the sector, not just in volumetric terms but also in terms of the impact on water stresses in key production areas.

Optimal social and environmental resource allocation in relation to global water use by the food sector will not be achieved, however, without policy interventions targeted at both the supply and demand sides of the economy. Even where virtual water trade results in water savings at an aggregate global level – through, for example, exporting food and agricultural products from places of more water-efficient production to places with lower water efficiency – production may nevertheless be based on unsustainable water use at a local level.

Carefully developed public sector and private sector policy interventions in and across multiple domains – trade, environment, agriculture, health – will be required to ensure that food and agriculture production and value chains are resilient to emerging water-related risks, and that they support rather than undermine sustainable water consumption by the food sector and other water users. In addressing these water-related risks, actors will need to consider the impacts on those who earn their livelihoods from the food system. They will also need to anticipate the broader environmental consequences of policy decisions.

Existing sustainability guidelines can support some such decisions, but a greater level of political attention and willingness to address some of the larger structural factors will be necessary. This includes ensuring that actions move beyond disparate interventions siloed in individual supply chains or government departments. Instead, a coordinated approach will be needed that aims for synergies between water, climate and biodiversity actions taken across government, between producer and consumer countries, and involving public sector and private sector entities.

As the Global Commission on the Economics of Water noted in its 2024 report,[89] trade and domestic policies need to reflect the true value of water to prevent water scarcity in exporting countries being exacerbated. If trade agreements are properly designed, they can create more balanced virtual water trade, helping to achieve sustainable water use globally. However, for this to be effective, domestic pricing of water needs to reflect the true economic, environmental and social costs of its use. If the opportunity costs of water use for the production and supply of exported (and domestically traded) goods are not accounted for, then distorted subsidies and incentives will prevent appropriate price signals being made.[90] Because of this, reforming or repurposing agricultural subsidies – whether those promoting water-intensive irrigated agricultural production in water-stressed regions, or supporting the overuse of inputs that degrade soils and contaminate waterways – should be a priority.[91]

Importing countries can also support sustainable water use in the prior segments of supply chains outside their jurisdictions. Among other measures, this should involve more closely linking trade and environmental policies. For example, mandating water footprint disclosures and instigating due diligence requirements and standards relating to the environmental and social impacts of water use and management in the supply chain can promote trade in responsibly sourced goods.[92] Such measures are likely to come with compliance costs, however, so streamlining

89 Global Commission on the Economics of Water (2024), *The Economics of Water.*
90 Ibid.
91 Ibid.
92 Weko, S. and Lahn, G. (2024), *Tackling trade-related water risks: How importing countries can address water stress from global commodity production*, Research Paper, London: Royal Institute of International Affairs, https://doi.org/.10.55317/9781784135966.

due diligence and disclosure regulations and coordinating social and environmental disclosure frameworks could be necessary to reduce regulatory complexity and lessen the reporting burden on suppliers.

Importing countries should also provide support to supplier countries to ensure that trade measures for sustainability are workable. This could help to forestall potential accusations of rich-country sustainability requirements disguising protectionism. Strong dispute-settlement mechanisms, combined with enforcement of penalties for non-compliance with environmental standards, will also be key.[93]

If it is to be successful, sustainable virtual water trade governance is likely to require a greater degree of diplomatic engagement, alongside technocratic regulation. As policy shifts to account more fully for environmental factors, the concerns of trading partners will need addressing sensitively and through diplomatic channels.

Plurilateral cooperation offers some possibilities for progress. For example, trust could be built through high-level forums such as the Trade and Environmental Sustainability Structured Discussions (TESSD) at the World Trade Organization. As a 2024 study by Weko and Lahn notes, discussions such as TESSD 'where developing countries are leading dialogues on trade and the environment have a critical role to play in improving engagement between trade partners'.[94] The study also argues that '[o]ngoing consultations can help to boost relations with partners for whom water-intensive goods make up a significant share of exports.' TESSD aims to identify actions that members can take individually or collectively, including ways to assess whether goods and services linked to biodiversity and natural resources can contribute to environmental sustainability and sustainable development.[95]

On the multilateral front, however, prospects for cooperation remain limited. In December 2026, only the third UN Water Conference since 1977 will be co-hosted by the United Arab Emirates and Senegal. The conference presents a rare opportunity for the international community to agree measures to accelerate implementation of Sustainable Development Goal 6, on ensuring the availability and sustainable management of water and sanitation for all. However, any commitments from member states will be voluntary and are likely to be piecemeal. In the prevailing context of weakened appetite for multilateralism, expectations for the conference should not be too high.

Nonetheless, nations seeking to raise the ceiling on what can be achieved through international cooperation, such as those that signed the Glasgow Declaration for Fair Water Footprints at the COP26 UN climate summit in 2021,[96] should continue to engage and learn from one another in and beyond such forums to ensure their trade dependencies – food and agriculture included – better support shared water security and drive global ambition forwards.

93 Ibid.
94 Ibid.
95 World Trade Organization (2025), 'Members deepen discussions on key sustainability topics and potential MC14 outcomes', 30 October 2025, https://www.wto.org/english/news_e/news25_e/tessd_30oct25_189_e.htm.
96 Fair Water Footprints (2021), 'The Glasgow Declaration for Fair Water Footprints for Climate-Resilient, Inclusive, and Sustainable Development'.

Annex 1. Unsustainable irrigation for non-cotton crops – the 20 most significant countries by four measures of global trade, bilateral trade and total production

Table A1. Unsustainable irrigation: four measures of global trade

	Unsustainable exports: volume		Unsustainable exports: fraction of total irrigation		Unsustainable exports: fraction of unsustainable production		Unsustainable imports: volume	
1	US	11.5 km^3	Qatar	73% (0.1 km^3)	Belgium	321% (0.0 km^3)	US	5.8 km^3
2	Pakistan	10.8 km^3	Israel	46% (0.5 km^3)	Austria	147% (0.0 km^3)	China (mainland)	3.9 km^3
3	India	6.6 km^3	Kuwait	38% (0.0 km^3)	Hungary	139% (0.0 km^3)	Japan	2.1 km^3
4	Mexico	5.8 km^3	Paraguay	33% (0.1 km^3)	Mozambique	132% (0.0 km^3)	Saudi Arabia	2.1 km^3
5	Spain	4.6 km^3	Belgium	31% (0.0 km^3)	Zambia	119% (0.0 km^3)	Canada	1.7 km^3
6	China (mainland)	2.4 km^3	Oman	27% (0.2 km^3)	Lesotho	100% (0.0 km^3)	UK	1.7 km^3
7	Egypt	2.2 km^3	Tunisia	26% (0.7 km^3)	France	97% (0.2 km^3)	France	1.7 km^3
8	South Africa	1.6 km^3	Spain	24% (4.6 km^3)	Russia	91% (1.4 km^3)	Mexico	1.7 km^3
9	Russia	1.4 km^3	Ukraine	23% (0.5 km^3)	Bulgaria	89% (0.0 km^3)	Italy	1.6 km^3
10	Morocco	1.4 km^3	Morocco	22% (1.4 km^3)	Qatar	84% (0.1 km^3)	India	1.6 km^3
11	Australia	1.1 km^3	Mexico	21% (5.8 km^3)	Portugal	80% (0.1 km^3)	Afghanistan	1.6 km^3
12	Iraq	0.9 km^3	Bulgaria	19% (0.0 km^3)	Israel	76% (0.5 km^3)	Netherlands	1.4 km^3
13	Saudi Arabia	0.8 km^3	South Africa	19% (1.6 km^3)	Paraguay	70% (0.1 km^3)	Russia	1.3 km^3
14	Argentina	0.7 km^3	Australia	18% (1.1 km^3)	Slovakia	69% (0.0 km^3)	United Arab Emirates	1.3 km^3
15	Tunisia	0.7 km^3	Mozambique	16% (0.0 km^3)	Romania	64% (0.1 km^3)	Indonesia	1.2 km^3
16	Canada	0.6 km^3	Russia	15% (1.4 km^3)	Cyprus	55% (0.0 km^3)	Kenya	1.2 km^3
17	Israel	0.5 km^3	Argentina	14% (0.7 km^3)	Zimbabwe	50% (0.0 km^3)	Germany	1.1 km^3
18	Ukraine	0.5 km^3	Canada	12% (0.6 km^3)	Tunisia	49% (0.7 km^3)	Turkey	1.0 km^3
19	Algeria	0.5 km^3	Yemen	12% (0.3 km^3)	Ukraine	48% (0.5 km^3)	Spain	1.0 km^3
20	Syria	0.4 km^3	US	11% (11.5 km^3)	Oman	47% (0.2 km^3)	Malaysia	0.9 km^3

Calculated from Rosa, L. et al. (2019), 'Global Unsustainable Virtual Water Flows in Agricultural Trade', *Environmental Research Letters*, 14 (11), 114001, https://doi.org/10.1088/1748-9326/ab4bfc.

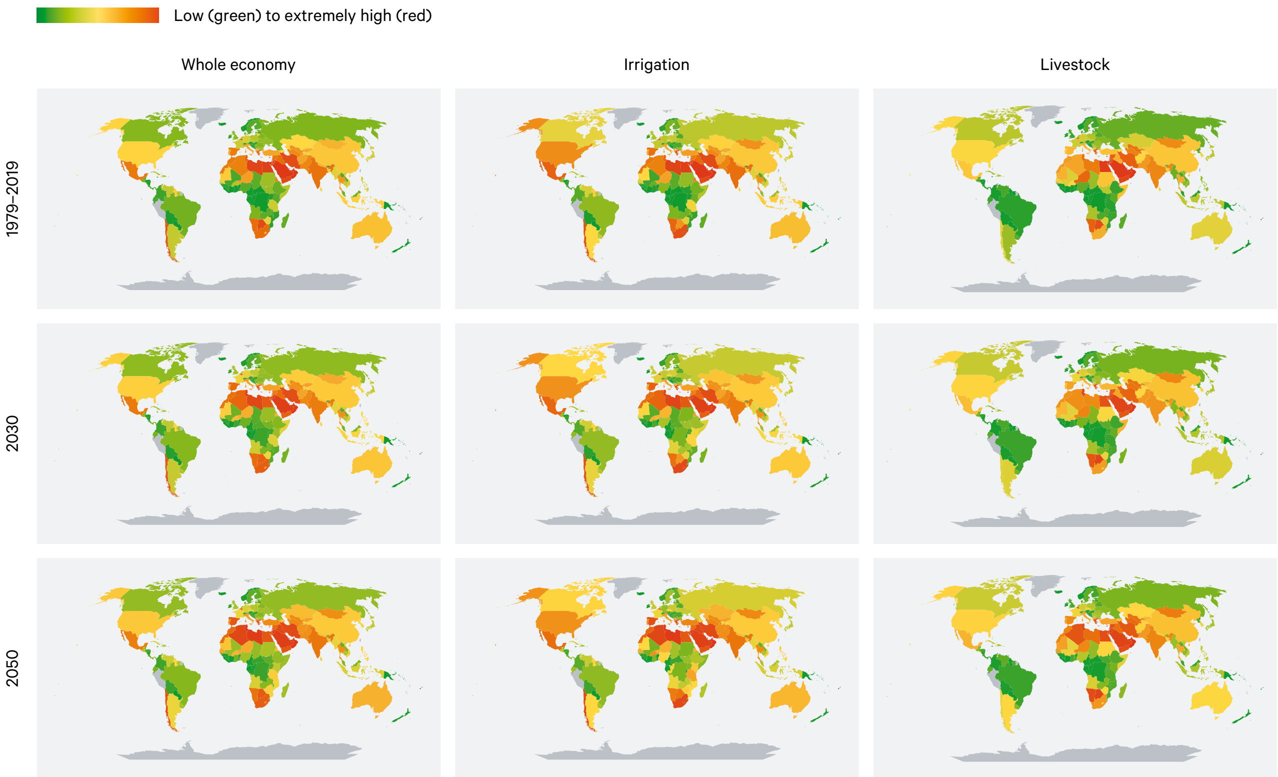
Table A2. Unsustainable irrigation: bilateral trades

	Exporter	Importer	
1	Mexico	US	4.5 km^3
2	US	China (mainland)	2.0 km^3
3	US	Mexico	1.6 km^3
4	Pakistan	Afghanistan	1.5 km^3
5	Pakistan	China (mainland)	1.4 km^3
6	US	Canada	1.3 km^3
7	US	Japan	1.3 km^3
8	Pakistan	Kenya	1.1 km^3
9	Spain	France	1.0 km^3
10	Iraq	India	0.7 km^3
11	Spain	Germany	0.6 km^3
12	Spain	UK	0.6 km^3
13	Russia	India	0.6 km^3
14	India	Saudi Arabia	0.5 km^3
15	Pakistan	Saudi Arabia	0.5 km^3
16	Pakistan	Malaysia	0.4 km^3
17	China (mainland)	Japan	0.4 km^3
18	Pakistan	Madagascar	0.4 km^3
19	US	South Korea	0.4 km^3
20	Spain	Portugal	0.4 km^3

Table A3. Unsustainable irrigation: production

	Unsustainable irrigation: volume		Unsustainable irrigation: fraction of total irrigation	
1	India	129.7 km^3	Saudi Arabia	100% (13.3 km^3)
2	China (mainland)	88.4 km^3	Libya	94% (3.0 km^3)
3	Pakistan	62.2 km^3	Yemen	88% (2.4 km^3)
4	US	60.0 km^3	United Arab Emirates	88% (4.2 km^3)
5	Egypt	18.9 km^3	Qatar	87% (0.1 km^3)
6	Iran	18.2 km^3	Kuwait	86% (0.1 km^3)
7	Mexico	17.2 km^3	Botswana	84% (0.0 km^3)
8	Saudi Arabia	13.3 km^3	Jordan	83% (0.7 km^3)
9	Uzbekistan	10.4 km^3	Morocco	83% (5.2 km^3)
10	Spain	9.8 km^3	Turkmenistan	73% (6.8 km^3)
11	Iraq	7.1 km^3	Australia	72% (4.6 km^3)
12	Turkmenistan	6.8 km^3	South Africa	72% (6.3 km^3)
13	South Africa	6.3 km^3	Djibouti	68% (0.0 km^3)
14	Morocco	5.2 km^3	Niger	66% (0.4 km^3)
15	Australia	4.6 km^3	China (mainland)	66% (88.4 km^3)
16	United Arab Emirates	4.2 km^3	Somalia	64% (0.6 km^3)
17	Sudan	3.8 km^3	Occupied Palestinian Territory	64% (0.1 km^3)
18	Kazakhstan	3.6 km^3	Mexico	63% (17.2 km^3)
19	Syria	3.3 km^3	Pakistan	62% (62.2 km^3)
20	Libya	3.0 km^3	Israel	61% (0.7 km^3)

Annex 2. Country-level baseline water stress (whole economy, irrigation, livestock) to 2050 under a business-as-usual scenario



Note: Business-as-usual (BAU) scenario reflects Shared Socioeconomic Pathway 3 (SSP3), combined with Reference Concentration Pathway 7.0 (RCP7.0). The SSP-RCP scenario framework is widely used by climate scientists, including within the Intergovernmental Panel on Climate Change (IPCC) assessment processes, to analyse the feedbacks between climate change and socioeconomic factors.

Source: World Resources Institute (2023), 'Aqueduct 4.0', https://www.wri.org/aqueduct (accessed 1 Sep. 2025).

About the author

Richard King is a senior research fellow in the Environment and Society Centre at Chatham House. His work focuses on the sustainability of – and systemic risks to/from – food systems, agriculture, land use and soft commodity resource trade. His recent projects have included examining cascading climate risks in international food trade; policy design in support of climate-smart and nutrition-secure food systems in southern and eastern Africa; and emerging sustainability issues associated with land-based approaches to negative greenhouse gas emissions. He was a lead author on the United Nations Environment Programme's flagship environmental assessment, Global Environment Outlook 6 (GEO-6, 2019).

Prior to joining Chatham House, Richard was deputy head of research at Oxfam GB, where he specialized in food and rural livelihoods, particularly in the contexts of climate change, resource constraints and market volatility.

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Cover image: A farm worker adjusts sprinkler heads spraying water on fields near El Centro, California, 18 October 2002.

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