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Earth Overshoot Day:
The Importance of Virtual Water

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INTRODUCTION

Every passing year, Ireland, Europe, and the entire globe experience the progressively frightening and increasingly extreme effects of climate change. Summer after summer, temperatures break previously held records, wildfires devastate wider and wider swathes of land, claiming lives and livelihoods from Norway, to Spain, to France and beyond. Water shortages and water restrictions are a common feature of even an Irish summer, with reservoirs at critically low levels, and water use far outstripping the amount of treated water available for consumption.

The advancement of technology, such as AI, presents incredible opportunities. However, there are real and hidden costs to advancement that are not as obvious as wildfires and record-breaking air temperatures, and these costs have existed long before the advent of AI. It is generally understood that the production of the things that we, as an ever-increasing population of humans, need to survive have a complicated impact on the environment, food production being one area often discussed in terms of methane emissions and direct water usage. Another less commonly known area is that of **virtual water**, which touches upon almost all aspects of human production and consumption.

WHAT IS VIRTUAL WATER?

Virtual water, a.k.a. “embedded water” or “indirect water,” is the water hidden in the products, services, and processes people buy and use every day. Virtual water is invisible to the end-user of a product or service, but has been used throughout the supply chain, so that the creation of that product or service possible. Basically, all goods and services that rely in one way or the other on the presence of water ‘contain’ a virtual amount of water. As such, virtual water is an important indicator in global water resource assessment (Hoekstra, 2003; Mekonnen et al, 2024; Oki et al, 2004).

By comparison, direct water use is the water that is seen and known to be used at a given time and location to produce an item or service (such as water from the tap, irrigation, water added to the brewing process for example, or in the production of dye for clothing, and the distilled water used in the production of computer chips). It is the water directly necessary to carry out an operation or activity. Virtual water is also distinct from the physical volume of water that may be contained in, for example, food commodities, such as the physical water content of a tomato (Ma et al, 2020; Aldaya et al, 2020).

Direct water is linked to virtual water: when we take all the direct water used to make a finished product, that total water can be considered the virtual water content.

HISTORY

The concept of virtual water originated in the 1990s, introduced by John Allan in 1998. It originated in the context of the debate on food security and trade in regions of extreme water shortage, such as the Middle East and North Africa. The original idea of virtual water was to assess the amount of water resources in the importing country that can be saved and historically was used as an adaptation strategy that enabled some arid regions to develop a successful and wealthy economy without putting pressure on their threatened and scarce water resources. In principle, throughout history this manifested as raw materials from water-abundant regions being imported to arid regions, which were then synthesized into more valuable commodities (Bhowmik et al, 2026). Hence, the trade in such water rich commodities to arid regions was as political as it was necessary throughout the course of modern industrialization around the world.

WHAT IS VIRTUAL WATER USED FOR?

In its crudest sense, virtual water is a form of water accounting. The basic idea of virtual water is that it is a mechanism to estimate a unit requirement of water resources used to produce a particular commodity, and a way to understand virtual water flow around the globe. You may be more familiar with the term "water footprinting", which like carbon footprinting, which is a method to assess the amount of water consumed to produce a product or service. Water footprinting also takes account of the water wasted in generating those products or services. This concept came into existence in the early 2000s and was correlated to virtual water (Liao et al, 2024).

It is vital for countries to know their water footprint as it helps to accurately assess their water resources, especially for those countries experiencing water crises (Hoekstra, 2003; Bhowmik et al, 2026).

Virtual water research is an interdisciplinary discipline involving hydrology, socio-economy, and the ecological environment, with methods developed for:

- virtual water accounting and calculation,
- scenario analysis methods to predict future virtual water flow trends,
- and methods to analyse virtual water flow paths and associated impact assessment.

Typically, virtual water has been discussed in terms of agriculture, forestry, industrial, and mining products. For example, the idea of virtual water evaluates the amount of water embodied in a crop that can be purchased internationally, with the amount of water which would be required to produce that crop domestically. For instance, for every kilogram of wheat (*Triticum aestivum L.)* imported, the water-stressed country will also get about 1 m^3 (1000 l) of virtual water at much less cost than the price or value of the same quantity of water from the local water resources, if available, in the country itself (Allan, 1999). Similar calculations can be made for other food items requiring greater amounts of water in the production process.

The textile and apparel industries are the second-largest consumers of water after agriculture. Textile businesses use a lot of water, but they also pollute the water with dyes, chemicals, and microfibers that damage the environment. Each year, these businesses release millions of liters of chemically contaminated water into the waterways (Liao et al, 2024; Hekmatnia et al, 2023).

VIRTUAL WATER TRADE (VWT)

Virtual water trade (VWT) means the exchanges of virtual water between different regions, via the trade of physical goods that have required water for their production. This idea was introduced to highlight the hidden water resources consumed by countries that import food produced abroad, and thus virtually import some of their trading partners' water resources (Liao et al, 2024).

It should be noted that the creator of the virtual water concept, Allan (2003), acknowledged that while virtual water is a useful concept for understanding the water-food-trade relationship, it can also be seen as a misleading metaphor if not applied carefully. He emphasized that virtual water should be used as a tool for water resource management and policy planning rather than a standalone solution (Sun et al, 2021).

SOURCES OF VIRTUAL WATER

Sources of virtual water can be divided into three main categories based on their origin:

1. Blue: water found on the surface of the earth, including groundwater. Heavily used in agriculture.
2. Green: water produced via plant transpiration, and rainfall in soil.
3. Grey: wastewater or water polluted due to human activity. Water that requires treatment (Persson et al. 2022).

Black water is a separate category of water so polluted it cannot be used for domestic or industrial purposes.

WHY IS VIRTUAL WATER IMPORTANT?

Virtual water offers meaningful insights into the complex interaction between water, trade and sustainability.

In part due to the development of Sustainable Development Goals in recent years, an increased focus on environmental sustainability, particularly regarding water sustainability, has emerged. As a result, virtual water has gained attention as a crucial tool for water resources management. Research into virtual water has made significant contributions with regards to quantifying the virtual water content embedded in commodities, defining international patterns of virtual water flows, revealing the temporal and spatial distribution patterns of virtual water trade, evaluating the economic value of virtual water, and analyzing the drivers influencing virtual water flows (Liao et al, 2024).

In terms of natural capital, water is pivotal and singularly essential for human survival, and the survival of all creatures and habitats. Water is pivotal in industry, manufacturing, food production, and medicine. Due to the rapid increase of the human population, urban sprawl, agricultural intensification, and technological advancement, freshwater resources are under acute and urgent stress. Hence, methods of identifying water stress are key, alongside policy and a willingness to respond. Virtual water still presents a systematic way to assess the complexity of water-trade relationships, while water footprinting makes it more intuitive for the majority of users, and enables individuals to understand their own water use.

CONCLUSION

Virtual water may be invisible, but its impacts are increasingly visible in the form of water scarcity, ecosystem degradation, supply chain disruption, and growing competition for freshwater resources. As climate change intensifies pressure on water systems across Ireland and the world, understanding where and how water is consumed becomes as important as measuring energy use or carbon emissions.

For engineers, designers, planners, and project managers, virtual water offers another lens through which sustainability can be assessed. Whether considering construction materials, technology infrastructure, manufacturing processes, or supply chain decisions, the ability to account for hidden water consumption supports more informed and resilient project outcomes.

While technologies such as AI promise significant benefits for society, they also remind us that every digital advancement relies on physical resources somewhere in the world. Data centres require cooling, semiconductors require ultrapure water, and global supply chains depend upon water-intensive manufacturing processes that are often hidden from end users.

Virtual water provides a framework for understanding these hidden dependencies. As we continue to innovate and embrace new technologies, sustainability discussions must extend beyond energy and carbon to include water. For organisations involved in shaping the built environment and critical infrastructure, recognising water as a finite and valuable resource is essential to delivering solutions that remain sustainable in a changing climate.

This article provides only a brief introduction to the concept of virtual water and its role in sustainability. Readers interested in exploring the topic in greater depth are encouraged to review the references below, which offer valuable insight into the research, methodologies, and applications discussed.

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