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Virtual Water as a Metric for Institutional Sustainability

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Abstract

Carbon and nitrogen footprints are increasingly common metrics used to consider the environmental impacts of activities and consumption by institutions; an institutional water footprint complements these assessments by providing a third metric: water use. This study calculated the water footprint of the University of Virginia (UVA) as a summation of direct water use and virtual water use. The latter was estimated using purchasing records for utilities, food, transportation, paper, research animals, and hospital purchases for calendar year 2014. The direct water use portion of the footprint was 1.7 million m^3 water. The virtual water footprint was 15.2 million m^3. The utilities sector is responsible for 46 percent of UVA's total water footprint, and food production 23 percent. The UVA Health System contributed 17 percent, and paper, transportation, and research animals each constituted less than 3 percent of the total footprint. The most water-intensive inputs were biofuels, hydroelectricity, and animal products. This water footprint assessment supports carbon and nitrogen footprint-reduction strategies, such as replacing coal with natural gas and reducing beef consumption. Water footprints also require explicitly considering the impacts of renewable energy sources, such as biofuels or hydropower. The water footprint of the University of Virginia provides an additional measure to address the environmental implications of the institution's resource demands and this approach is broadly applicable to other institutions.

Keywords: indirect water; institutional footprint; virtual water

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Introduction

The average American uses about 200 liters of water per day through the tap by flushing toilets, bathing, drinking, and cleaning. This use is just a drop in the bucket compared to virtual water, the water incorporated into growing agricultural items and producing manufactured commodities, which is 7,800 liters per day for the average American.[1,2] Recent virtual water footprint studies have mapped international trading of virtual water from import and export data,[3–5] evaluated the global sensitivity of crop water requirements,[1,6] and estimated the virtual water impacts of individual purchasing behavior.[2,7] Most studies, to date, focus on regional-scale direct and virtual water use, but similar studies are possible at the institutional scale and can be used for sustainability assessments. This study estimated the total water footprint of the University of Virginia.

Universities can be leaders in the development of (internal) sustainability policies that are subsequently adopted by other institutions, similar to recent and ongoing divestment campaigns in "unethical" businesses (including fossil fuel assets) that often started with university endowments and then spread to the wider market.[8] Indeed, by pioneering divestment efforts (e.g., in fossil fuels, tobacco, or apartheid-related business), some prominent American universities have set the standards for responsible investments.[8] Likewise, by taking the lead in initiatives that evaluate and possibly minimize their environmental impacts, universities and other organizations may become role models in the development of

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strategies to monitor and reduce their carbon, nitrogen, and water footprints, while educating students about the environmental impacts of consumers' decisions.

Thousands of colleges and universities in the United States monitor their institutional greenhouse gas emissions to consider their institution's contribution to global climate change.[9] Carbon footprints emphasize the impacts of energy and transportation. A nitrogen footprint evaluates the reactive nitrogen lost to the environment, which causes eutrophication, smog, and stratospheric ozone loss.[10,11] Nitrogen footprints correlate with carbon footprints in regard to energy use.[12] The Nitrogen Footprint Network emphasizes the impacts of food purchasing, and for seven of the colleges and universities included in the network, food accounts for 35 to 82 percent of the total nitrogen footprint.[11] Galli et al. contend that ecological, carbon, and water footprint strategies generate a well-rounded assessment of human pressure on the environment.[13]

A complete water footprint accounts for both direct and indirect water consumption. In a university setting, direct water use is primarily from chiller plant demand and residential use in dormitories. Indirect water consumption is the virtual water incorporated into the production and manufacturing of goods that are sourced from around the world. In this study, *indirect* and *virtual* water consumption are used synonymously.

There are three categories of virtual water: green, blue, and grey. Green water refers to water provided by precipitation and is most often noted in studies on agricultural and forestry products. Blue water is the surface or groundwater that is extracted and used for production, such as irrigation for crops, extraction of fossil fuels, and manufacturing of paper.[1,2] Grey water is the water needed to remediate water pollution to meet clean water standards, including nutrient pollution in agriculture and manufacturing pollution from paper mills. Grey water is especially complex to address, as countries across the world have varying standards for nutrient pollution and because runoff and air pollution are difficult to inventory.[14]

The objective of this study was to calculate indirect water use from energy, food, and material consumption along with direct water use for the University of Virginia (UVA) for 2014. The resulting water footprint may be a tool to consider environmental demands of university purchasing behaviors. Many colleges and universities, including UVA, use carbon reporting as a tool to direct initiatives for institutional sustainability. UVA committed to reduce carbon and nitrogen emissions by 25 percent from 2009 and 2010 levels, respectively, by 2025, and utilities and food are key sectors that are projected to shift to meet that goal.[10,11] In addition to developing a water footprint, the alignment of water with carbon and nitrogen footprints was considered, including the areas in which strategies for reducing footprints differ.

Methods

UVA is a public institution in Charlottesville, Virginia, with over 22,300 students enrolled in undergraduate and graduate programs. The campus includes the UVA Health System, with a census of 446 patients per day in 2014.[15] The UVA water footprint includes direct water use and virtual water estimates. Direct water use for 2014 was reported from the Facilities Management water bill, and included all water consumption in central Grounds—including academic quarters, residential areas, and the UVA Health System.[16] The following sections detail the analysis of UVA's virtual water consumption from university purchases for routine operations. Infrastructural materials such as asphalt, brick, and furniture were not included. Most categories overlap with those used to estimate the carbon and nitrogen footprints,[10] namely utilities, transportation, and food. Water-intensive products derived from paper and cotton were added to the calculation to assess their significance relative to the total footprint.

Utilities

On-grounds utilities use a fuel mix of coal, natural gas, propane, and distillate oil. In 2014, the fuel mix for electricity purchased from Dominion Power was 27 percent natural gas, 27 percent coal, 39 percent nuclear, and 7 percent renewables.[17] Dominion Power's renewable electricity production reported that for 2014, the total electricity mix was 4 percent hydroelectricity, 1 percent recycled wood, 1 percent landfill gas, and 1 percent wind and solar.[18]

The virtual water factors for fossil fuel products were median values derived from global assessments. These factors vary by extraction location and method, fuel transport, and power plant structure.[14] Renewable energy sources vary in size for virtual water demand per unit of energy, from water-intensive biofuels to water-efficient wind power.[1,14] A study of American reservoirs[19] identified rates of evaporation and virtual water loss for the nearby state of North Carolina, thus a factor of 0.0395 m^3/kWh was used in the

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Table 1. Water Factors for the Utility Sector by Energy Source

Energy Source	m^3 Water/TJ	Reference
Electricity - Natural gas	658.0	14
Electricity - Coal	1,094.5	14
Electricity - Nuclear	763.0	14
Electricity - Hydropower	10,902.8	19
Electricity - Biomass	293,500.0	14
Electricity - MSW & Landfill Gas	0.0	14
Distillate Oil (#1-4)	728.0	14
Natural gas	658.0	14
Propane	728.0	14
Coal	1,094.5	14

university footprint calculation. Landfill gas was assumed to have a virtual water factor of zero. (See Table 1 for water factors for energy sources.)

Food

UVA's food purchases, including dining hall service, catering, and other contractual retailers, were inventoried in the 2014 UVA Nitrogen Footprint project.[11] The data set categorized food mass into 18 categories, including poultry, bovine, milk, cheese, cereals, fruits, pulses, and stimulants such as coffee and chocolate. Multi-ingredient items were separated into their respective categories by proportional weight.

The Virtual Water Network Waterstat Database[20] provides virtual water factors for crops from nations and regions across the globe. This study used the U.S. national average, as regional data for food purchases were not available from dining services. To create a virtual water factor for each food category, a weighted average was determined using production weights from the Food and Agriculture Organization database[21] with corresponding virtual water factors for United States agricultural production.

The indirect water footprints for stimulants, fish, and beverages were broken into subcategories, as these sectors are complex and often sourced outside the United States. Water factors for coffee and chocolate within the stimulants category were a global average, as production is constrained by region. Marine and wild-caught fish were considered to have a virtual water footprint of zero.[22] Gephart et al. evaluated top-cultivated aquaculture products to estimate the quantity of feed and respective water required to grow feed, and this estimate was used for tilapia.[23] Most fish were marine, and at the time of this study, there was no water factor research for seafood. Beverages with high sugar content, like Gatorade and soda, were assumed to be corn syrup products since they were produced in the United States, where corn is the most common sugar source.

The study also accounted for food transport, assuming transportation occurred by diesel vehicles with a capacity of 22,700 kilograms of food and 5.3 liters water per liter fuel.[24-,26] Standard food miles range was 105 to 2,414 kilometers, and the assumed mileage for all items was 1,609 kilometers.

Transportation

The virtual water account for transportation included direct gasoline and diesel purchases for university buses, facilities fleet vehicles, the university jet, along with estimated fuel consumption from commuter travel. Gasoline, diesel, and jet fuel were assumed to have a water factor of 5 liters water per liter of fuel, while biodiesel had a water factor of 2,508 liters of water per liter of fuel.[24,26]

Paper

Paper consumption was estimated from a UVA 2014 recycling report, which indicated a total 1,240 metric tons of corrugated cardboard, white ledger paper, and mixed paper were recycled.[27] This paper estimate was assumed to represent 34 percent of paper used at UVA, the national recycling rate reported by the Environmental Protection Agency.[28] Thus the total paper consumption was estimated to be about three times that which was recycled.

Paper was assigned a water factor of 5.5 m^3 water/ ton paper.[29] Although virtual water factors vary slightly with the recycled content of paper, this general water factor was assumed for all paper types.

Research Animals

Purchasing records of feed and bedding were used to estimate the water footprint of research animals.[30] The feed was for mammals, primarily mice and swine, thus it was assumed to have a concentration of 80 percent cereals, 15 percent pulses, and 5 percent pig meat by weight.[31] The bedding records indicated material was either a paper or corn product. The categorical virtual water factors for cereals, pulses, pig meat, and corn utilized in the food calculation were used to compute the virtual water of

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the feed and bedding. The water used to hydrate the animals was incorporated into the direct water measurements for the university.

UVA Health System

Estimates of cotton use for the UVA Health System were calculated using linen weights from the linen cleaning service.[32] Linen composition was estimated with reviews from Value Management at the UVA Health System, and hospital supply retailers report that sheets were 55 percent cotton.[33] To account for the lifetime of the linen materials, the total cotton weight was divided by five, the average number of years a linen product is used in hospital services. The virtual water factor of cotton-based manufactured textiles is 8,099 m^3 of water per ton of fabric.[1]

Paper products such as toilet tissue, paper towels, etc. are extensively used in the Health System. Ten of the most-purchased paper products, including various brands of tissue products, were used to estimate paper weight.[34] Paper virtual water was computed using the same virtual water factor as in the Paper section, 5.5 m^3 virtual water/ton paper.[29]

Purchasing records for food consumption from cafeteria services and room service were used to estimate virtual water using the same procedure as described in the Food section.

Due to the difficulty of drawing system bounds between the Health System and university for utilities, the utilities sector accounts for all utilities across the Health System and the university.

Uncertainties

Some carbon and nitrogen footprints provide credit systems for material and food recycling; no credit system was devised in this study. Records for 2014 indicate that 11 percent of food purchased was composted or donated. Scaling this food waste into categories proportional from the Food section above, the virtual water associated with compost and donations is 435,000 m^3, which would account for just 1 percent of the total university water footprint.

Error estimates were not considered in this footprint calculation, though there is potential error in both the data sets and the water factors. The data sets were based on purchasing records, though paper and Health System calculations were scaled estimates. The scope of this study was limited to these purchasing records and doesn't account for $2 million in office supply purchases,[32] the UVA Bookstore sales, off-campus medical facilities, or the satellite campus in Wise, Virginia. The origin of most resources consumed for 2014 is unreported, thus water factors were national (i.e., agricultural products) or global estimates (i.e., natural gas and coal). Reports cited in this study suggest that their respective factors may be underestimates.[1,4,14,19,22,23] For example, grey water is not included for fossil fuel factors or most food products.[1,14] Thus, the UVA 2014 water footprint is likely an underestimate.

Results

The total water footprint at UVA in 2014 was 16.9 million m^3 of water (Figure 1, Figure 2, Table 2). Of this, 10 percent is direct use, and 90 percent is indirect use. Electricity, on-campus utilities, and food were the largest components of the footprint. Electricity was the leading consumer of virtual water, and the largest contributor within that category was wood (Figure 3).

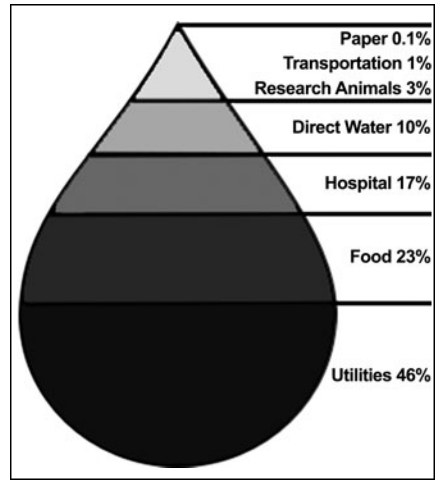

Figure 1. The total water footprint for the University of Virginia in 2014 was 16.9 million m^3, broken down by percentage here.

Wood provided 1 percent to the total electricity mix, but constituted one third of the total university water footprint. More than half of the virtual water from food was from animal products such as bovine, poultry, pig meat, cheese, eggs, and milk products (Figure 4). The transportation, paper, and research animal sectors each accounted for less than 13 percent of the total UVA footprint.

Discussion

As the first study assessing the direct and indirect water footprint of a university, these results serve as a model for other institutions considering the impact of their activities on water resources. The role indirect water plays points to the importance of including purchases of energy, food, and other water-intensive products in the full picture of institutional sustainability.

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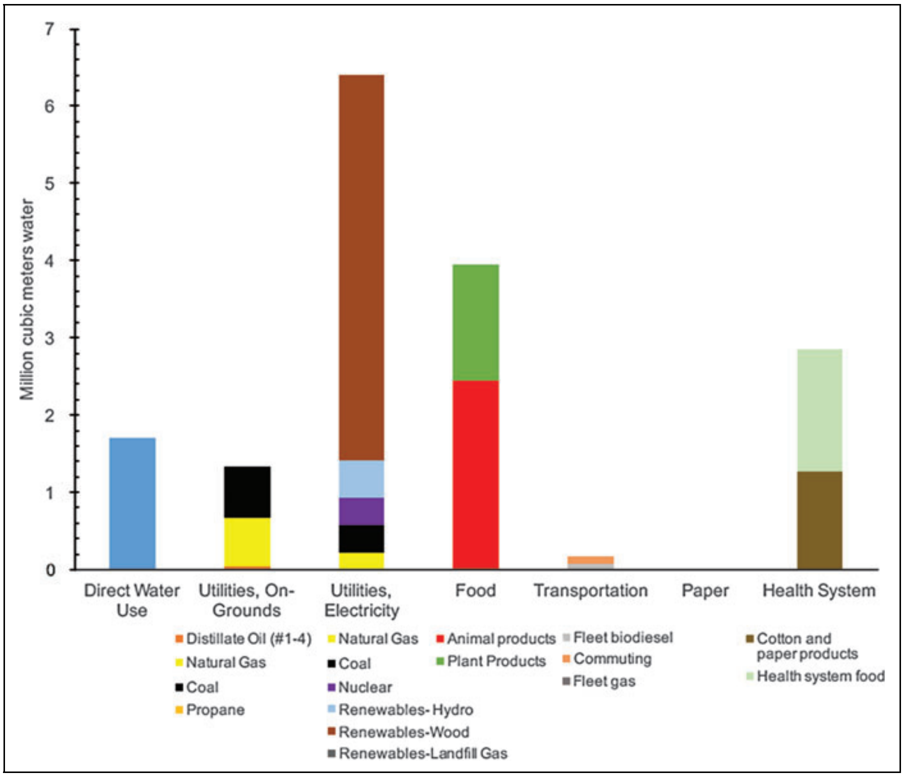

Figure 2. Each legend corresponds only to the bar above it. Direct water use was 1.7 million m^3. Utilities includes the on-campus heating plant (1.3 million m^3 water) and purchased electricity (6.4 million m^3 water). Food constitutes 4.0 million m^3 virtual water. The remaining portion of the water footprint was 170,000 m^3 from transportation, 20,000 m^3 from paper consumption, 480,000 m^3 water from research animals, and of 2.8 million m^3 from paper, cotton, and food products consumed within the hospital.

Utilities

Electricity purchased from Dominion Power represented 6.4 million m^3 indirect water use, 37 percent of the total 2014 water footprint. The electricity mix was 4 percent hydropower and 1 percent wood biomass. However, these renewable energy sources account for 70 percent of the virtual water associated with electricity. Alternative sources reported factors eight orders of magnitude larger than those cited in the Methods section, as the hydroelectricity factor varies with climate and geographic conditions.[14] This factor strongly varies with climate and geographic conditions. This study used estimates for North Carolina because they are from reservoirs in the same climatic region. Compared to the global average, these estimates appear to be extremely conservative.

Wood was combusted at Dominion Powers' four dual coal and biomass power plants.[18] This wood biomass is sourced from forests after roundwood extraction, as the "smaller tree tops and branches left behind after round wood harvesting" are considered waste.[18] If truly considered as a waste product, this wood could have a water footprint of zero. However, utilizing the wood virtual water factor as cited by Mekonnen, Gerben-Leenes, and Hoekstra makes the case that growing forests for fuel is not a water-efficient option for energy production.[14] They suggest that landfill gas has a water footprint of zero, as the methane is an inevitable by-product that cannot be grown like biofuel. Excluding landfill gas, the energy sources that have the lowest virtual water use per unit energy are fossil fuels, where coal is the most water intensive and natural gas the least. The small volumes of propane and distillate oil combusted in the heating plant contributed negligible quantities of water to the total footprint.

Unlike UVA's carbon and nitrogen footprints, the water footprint of biofuels and hydroelectricity is a more significant portion of the total footprint than that of fossil fuels.[10] Despite the respectively small water demands of fossil fuel extraction, transportation, and combustion, the water footprint of fossil fuels would be several magnitudes larger if the

Table 2. University of Virginia Water Footprint, by Sector

Sector	Virtual Water (m^3)	% of Total
Direct Water	1,700,000	10.06
Utilities	7,738,501	45.77
Food	3,945,642	23.34
Transportation	171,712	1.02
Paper	19,974	0.12
Research Animals	476,218	2.82
Hospital	2,854,254	16.88
Total	16,906,301	100.00

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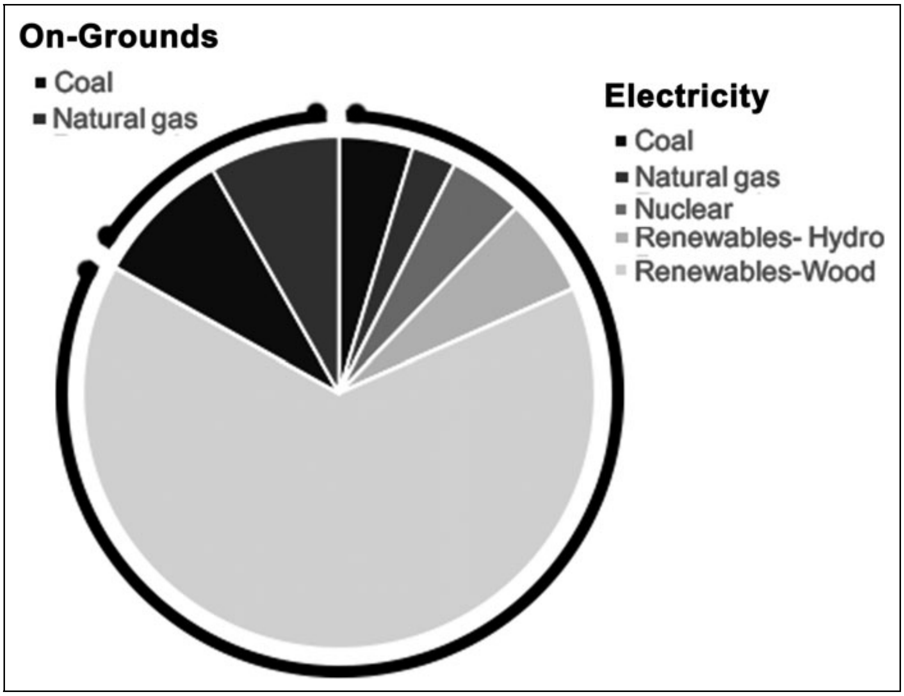

Figure 3. Electricity is 83% of the total utilities virtual water use. Hydroelectricity and wood, both renewable energy sources, account for 70% of the virtual water from utilities. Landfill gas had a water footprint of zero, and thus is not included. Propane and distillate oil were combusted in on-campus heating, but contributed less than 1% to utilities' indirect water, and are also not included.

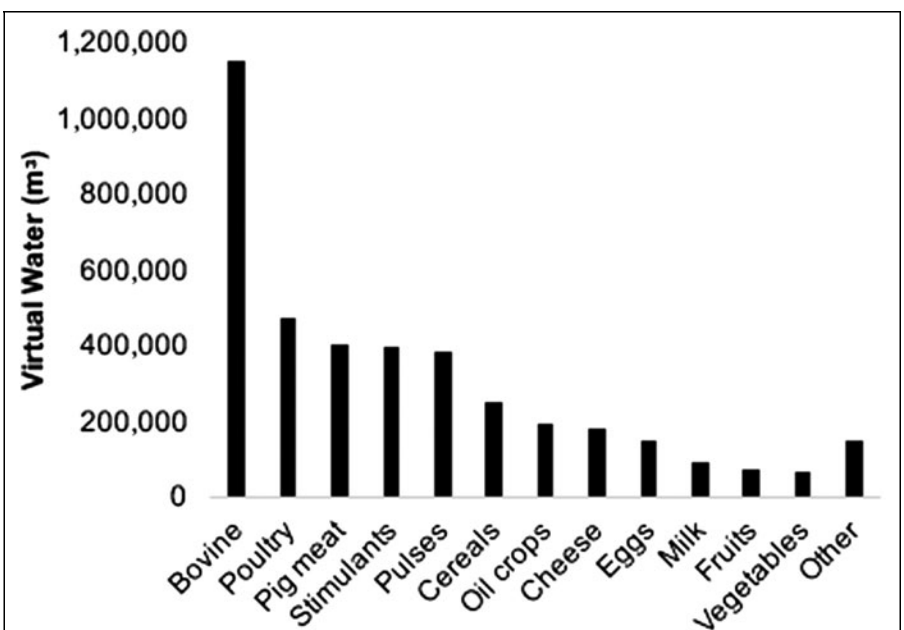

Figure 4. Virtual water from food, 2014, totals 3.9 million m^3: bovine products, poultry, and pig meat constitute 51%; food virtual water, and cheese, eggs, and milk 11%; stimulants 10%; pulses 10%; and cereals 6%. The "other" category includes nuts, starchy roots, beverages, sugar crops, spices, and fish.

ancient fossil water which grew the plant matter were taken into account.[35] The virtual water footprint recognizes environmental impacts of these renewable energy sources, which are not as significant as those using carbon and nitrogen metrics.

Food

The virtual water of food is 23 percent of the total university water footprint. Animal products are the largest component of virtual water from food, and the bovine sector alone is one third of the total food footprint (Figure 4). Stimulants, pulses, and cereals are the next most water-intensive crops after meat products. Nuts and poultry are the most water-efficient protein sources, evident by their water factors. Farm-raised tilapia had a lower footprint per unit weight than other animal proteins. However, little research regarding marine fish water footprints is available. Of the total virtual water from food, merely 61 m^3 is due to food transportation.

Transportation

The commuting sector makes up about half of the total 170,000 m^3 indirect water from transportation. University-owned vehicles and the university jet account for the remaining 46 percent of transportation-associated water. The transportation computation includes biodiesel in university vehicles, diesel in university vehicles, and gasoline for commuters. Biofuels are more water intensive per mile than petroleum products, as the green and blue water used to grow biofuels is significantly larger than the water required to extract and process petroleum products.

Paper

Preliminary estimates of paper consumption categorized $2 million in

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office supply purchases from the 2015 fiscal year.[36] These purchases constitute less than 40 percent of the university's office supply expenditures. The calculation included in this study used paper recycling rates scaled with the assumption that paper recycling rates reflect the EPA's national average of 34 percent. The total virtual water calculation from the recycling rates method is nearly five times the volume of virtual water calculated from purchasing-record estimates. The recycling calculation was considered a better representation of paper use because it incorporates shipping cardboard and paper purchased outside the university. Despite the variability between these methods for paper weight estimates, the paper calculation is not a significant contribution to the total water footprint.

Research Animals

Virtual water associated with research animal feed and bedding is 3 percent of the total footprint. A calculation approximated by estimating food requirements at 2 percent of the animal's body mass used 14 times less water and was assumed less accurate than the purchasing-record method detailed in the Paper section.

UVA Health System

Linens, paper products, and Health System food service contributed 17 percent to the total footprint. The paper calculation was likely an underestimate, as only the top 10 paper products purchased were inventoried, and shipping materials, packaging, and printing paper were not included. Health System food service was included in this sector instead of the general food category because the academic dining food services are managed separately from the Health System food services.

Conclusions

UVA is already committed to reducing its direct water use to 40 percent below 1999 levels by 2025.[37] The findings of this assessment of UVA's 2014 water footprint point to several management strategies that have the potential to reduce UVA's indirect water footprint. Electricity and food were the largest components of UVA's water footprint, and similarly, these are the primary focus areas for carbon and nitrogen footprint reductions. Natural gas is the lowest impact fossil fuel energy source in carbon, nitrogen, and water sectors. Thus a shift to natural gas from coal would be beneficial for all three footprints, and indeed UVA has outlined operational goals to eliminate on-campus coal in the Greenhouse Gas Action Plan.[38] Wood pellets, switchgrass, and other biofuels are growing areas of interest for energy and transportation. They prove costly in terms of virtual water and nitrogen. The impact of hydroelectricity projects varies widely across the United States. Many hydroelectricity plants, like those in Virginia, were built 30 to 60 years ago, and replacing an equivalent quantity of energy from another sector would be resource intensive. Although hydroelectricity is a large contributor to UVA's water footprint, these old reservoirs are low impact in the nitrogen and carbon sector. Food is a focal point in many institutions' sustainability initiatives and is essential to nitrogen and water footprint reduction. For carbon, nitrogen, and water alike, bovine products could be replaced with chicken or nut protein, which are the most efficient protein sources for all three footprints.

This assessment of UVA's institutional direct and indirect water footprint shows the stark contrast between on-site water use and the virtual water embedded in commodities consumed by the university. It also reveals drivers of institutional indirect water footprints, some of which align with other campus sustainability metrics (e.g., food), while others show significance only through virtual water (e.g., renewable energy, biofuels). Because of the drivers that are unique to institutional indirect water footprints, the indirect water footprint is a powerful tool to add to existing carbon, nitrogen, and direct water footprint assessments. Extending this type of virtual water footprint assessment to institutions beyond UVA will provide valuable insight into additional drivers. Incorporating this virtual water assessment into UVA's sustainability activities will strengthen the university community's understanding of how its activities contribute to resource use and the respective impacts on human and ecosystem health beyond the campus of its immediate geographical setting.

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