**Virtual water supply chains diversity buffers cities of the Global South against climate change**

**Abstract**

Water had a great influence on the rise and collapse of ancient civilizations. Nowadays, mankind faces water-related problems exacerbated by intensive farming, rapid urbanization, and climate change strikes. The world’s population is becoming increasingly dependent on water resource. However, most of the water humanity is currently consuming is invisible in nature, and we know less how this virtual water is circulating within the global economic supply chains. While the water footprint of cities of the Global North are profoundly analyzed, Global Southern cities remain poorly documented. To bridge this gap, we compute and decompose cities’ virtual water (Bleu and Grey) of the Global South, we used Extended Environmental Input-Output Analysis (EE-IOA). While the scientific literature asserts that North Africa is triggered as a climate change hotspot that is exposed to strong temperature increase and high drought risk, North African cities are importing more goods and services that contains larger amount of freshwater to reduce the burden of climate change and preserve local freshwater for drinking. Results showed that the average, across all the selected cities, virtual bleu water is estimated to 253 liters per capita/yr and for grey water is estimated to 285 liters per capita/yr which means that cities of the Global South are causing transboundary water pollution more than they import fresh water embedded within products and services. When decomposing the virtual water of the Global South we found that the major responsible sectors transport accounts for X% of the total footprint, followed by X with x% and x with X%. To place the climate-induced uncertainties in perspective, it is better to act in a pro-active approach and spread environmental consciousness regarding the purchase of products and services that are associated with less virtual water intensities (both Blue and Grey).

**Keywords**

Virtual water; input-output analysis; cities; water security; urban sustainability; Global South.

**Graphical abstract**



1. **Introduction**

**The status of water and the role of global warming**

Water is a finite resource and plays a major role in urban development and ecosystems sustainability. Thorough history, the first mankind’s revolutions testify on the relevance and the safety of water as resource (e.g., ancient human civilizations: Mesopotamia, Egyptian, Greek and Roman). 97% of the water on Earth is saltwater, leaving only 3% as freshwater, only 1% of which is readily available for human consumption.

The World Water Council’ Vision Report stated that there is a water management crisis which led both billions of people and the environment to suffer.

Therefore, new optimistic scenarios of climate change coupled with irrigation technologies are required (Harmanny and Malek, 2019)

According to the World Water Council, XXX live without a cleaned water, ….etc (set countries too). From a planetary scale, agriculture is ranked the first for consummating water with …… However, these values are biased in industrialized countries, where the industry accounts for ½ of the total water consumption.

Food price, food security, social stability

Yet, the direct water is clearly stated and monitored but what about the virtual water, the water we don’t see.

The world’s population is becoming increasingly dependent on this valuable resource. Water is considered to be a *“human right”* that is currently under sever strikes. The Millennium Development Goal defined *water security* as *“access to safe drinking water and sanitation”*.

Health problems and environmental risks can be abstained.

Unfortunately, we’re living in a changing climate, climate change is currently effecting water planning include changes in precipitation events, runoff patterns, and droughts. Despite recent advancements in climate research, there is still a lot of uncertainty about how and when the climate will change, and how these changes will affect water availability within an increasing demand for water, worldwide. Climatologists have blown the whistle regarding the perturbation of rainfall amount from year-to-year and there will be heat waves accompanied with drought episodes (Cook et al., 2016; Lelieveld et al., 2016).

Many areas around the world are facing water-related issues such as Cape Twon in 2018 where the city experienced the Day-Zero.

**Virtual water, what does it means?**

Contrary to the direct water that is used to produce commodities, goods and services, for instance, a car manufacture uses direct water throughout the production processes including surface treatment, paint spray booths, coating, washing, hosing, and rinsing that happened inside the manufacturing facilities. Summing up together, the value display the required amount of water to produce a product (a car in this example), that total is “virtual”, given the fact that the final consumers (owner of a car) it not aware of such water consumption; moreover, the final user also uses direct water (which stays qualified as “directed”) while using the car including washing, cooling, air-conditioning system. The virtual water, also known in the scientific literature as indirect, embedded, embodied water, is the quantity of water that has been consumed across the value chain of goods and services purchased from the global economic market, and it is often hidden from final consumers.

Despite the existence the existence of the Virtual Water Trade (VWT),

However, virtual water (also including virtual carbon, energy, nitrogen, phosphorus, human appropriation …) is not yet regulated by any national or international protocol.

**The role of water in urban development and sustainability future (urban metabolism approach)**

Supply and demand for water encompasses other non-climatic factors that might have a considerable effect on water including demographic growth, economic growth, affluence, and geopolitics. Cities are hyper-complex system that require inputs from the national and international markets to satisfy their development needs.

In addition, water pollution is increasing across the world which further shrink the available water for anthropogenic activities.

Water supply is bound with time, geography and climate hazards; therefore, societies of the global south should innovate new lifestyle patterns and

Developing economies are trying to grow so fast, without paying attention to the environmental degradation generated during this process.

**The novelty of this article**

The novelty of this study is that it computes the different types of virtual water namely blue and grey water for 181 cities belonging to the Global South (focusing on Upper Middle-Income -UMICs- and Lower Middle-Income -LMICs- classes) and decomposes each water footprint by major final consumptions categories (construction, electronics, food, goods, services, Transport, and Others) in order to allocate responsibilities to final demand sectors and trigger potential policy leverages. The final sample used for our analysis is based on 181 cities belonging to the Global South covering 23 countries and representing X% of the world’s population.

1. **Methods and Materials**

**Data collection**

To answer our research questions, two types of data were harvested. The first is urban expenditures surveys (UES) or consumers expenditures surveys (CES) (also denoted as city final demand vector - -) following COICOP-categorization of the 181 selected cities belonging to 23 countries belonging to the Global South, see electronic supplementary information (ESI) file for further details. Data were retrieved from the office of statistics of each host-country. Notice that data collection methods and quality may vary from a country to country, hence, from a city to city (took as-is). Because of data scarcity in the Global South, cities final demand vectors - - were not taken at the same year because of the internal protocol of each host-country to establish and deploy the consumer expenditures surveys, some countries establish the surveys annually, while others quinquennial as such several limitations are to encounter while comparing results among selected cities (also highlighted in (Hachaichi and Baouni, 2021, 2020)). The second data constitutes of global Multi-Regional Input-Output (MRIO) tables which were retrieved from Eora global supply chain database (Lenzen et al., 2013, 2012). Eora provides multi-region input-output table (MRIO) model that provides a time series (from 1990 to 2021) of high-resolution Input-Output (IO) tables (capturing the inter-sectoral transfers amongst 15,909 sectors) with corresponding environmental and social satellite accounts () for 190 nations. We used Input-Output tables (version 199.82) harmonized to 26 sectors to enable a transparent and an accurate comparison across selected cities. Notice that the current virtual water estimations of the Global South exclude footprints attributable to (i) government final consumption and (ii) gross fixed capital formation for which city-specific data was not available.

**Method**

For this study we used an Environmental Extended Input-Output Analysis (EE-IOA) (Haberl et al., 2019; Kitzes, 2013; Miller and Blair, 2009; Raa, 2006, 2007). Our analysis process is divided into two parallel pre-processing steps (Fig.1). The first in which we collected raw CES data in local currencies and transformed into cities’ final demand vectors () that matches to the respective sectoral used by Eora (26 sectors), we aggregated the values (via a distributive process) to match Eora 26 sectors classification by constructing “correspondence table” that maps each value from the raw CES data to match Eora’s sectors. To use the virtual water coefficients provided by the Eora satellite accounts (), we converted cities’ final demand arrays () from local currencies into $US using the World Bank exchange rates (World Bank, 2021) and were mapped accordingly to the national import structure for each country to be used in the input-output calculations. In the second step, we computed the direct intensity vectors () as shown in Equation (1) (for each year corresponding the selected city’s final demand vector) for each virtual water category (Grey, and Blue water), after we computed the final demand vector () using the Leontief inverse (Leontief, 1986) as shown in Equation (2).

…(Eq.1)

… (Eq.2)

Next, cities final demand vectors - - were converted from purchases price (PP) to base price (BP) on a sector by sector basis using national BP/PP ratios computed from Eora’s Multi-Regional Input-Output (MRIO) tables as preformed in (Pichler et al., 2017). To compute cities’ virtual water footprints (for each sector), we multiplied element wise the total demand vector () with the city final demand vector () as shown in Equation (3).

... (Eq.3)

Where is the virtual water per capita for a given city (m3/year), is the total intensity vector, and is the city final demand vector ($US/year).

**Diagram, schematic

Description automatically generated**

**Figure 1:** Method utilized to compute cities’ virtual water of the Global South and data dissemination by final major consumption categories.

1. **Results and discussions**

We will discuss the results of 181 cities’ virtual water of the Global South in section (3.1) while decomposing each footprint (Blue and Grey) by major final consumption categories, income class, geography, and major industrial classes. Next, in section (3.2) we will shed the light on the leverage points to design effective policies to reduce the virtual water alongside what are the handicaps policymakers encounter while designing strategic multiscalar policies.

* 1. **Urban virtual water of the Global South: Learning from contexts**

Results (Fig.2) shows that, on average, Global Southern cities’ virtual blue water footprint is estimated to 93 ± 78.5 liters per cap/year, and for the Grey water footprint is estimated to 133 ± 144 liters per capita/year. This finding shows that, on average across all selected cities, cities of the Global South are causing water pollution, elsewhere on the globe, more than importing fresh water embedded within goods and services. However, it is important to highlight that several Asian cities are associated with highest grey water footprints such as Atolls (Maldives) with 668 liters per capita/year, followed by Chinese cities Beijing, Guangdong, Tianjin, Jiangsu with 623, 517, 487 liters per capita/year, respectively.

Diagram

Description automatically generated

**Figure 2:** Distribution of virtual water across selected cities of the Global South by type (blue and grey).

Decomposing the virtual water footprints by income classes by Lower Middle-Income -LMICs- and Upper Middle-Income -UMICs- (Fig.3) showed that for blue water footprint, Upper Middle-Income countries of the Global South, across all the selected cities, is estimated to 104 ± 72.2 liters per capita/year, and to 166 liters per capita/year. Whereas for Lower Middle-Income countries of the Global South we found that the blue water footprint is estimated to 72.4 ± 86.4 liters per capita/year, and the grey water footprints is estimated to 70.4 ± 45.9 liters per capita/year. Our results corroborate other research (Fu et al., 2022; Hachaichi and Baouni, 2020; Hoekstra and Mekonnen, 2012; Lenzen and Foran, 2001; Pichler et al., 2019; Souissi et al., 2022; Weinzettel et al., 2013) whereby affluence is a driving force for environmental footprints.

A picture containing text, map, sky, light

Description automatically generated

**Figure 3:** Distribution of virtual water across selected cities of the Global South by income class (Lower Middle-Income and Upper Middle-Income).

From a regional perspective (Fig.4), we decern that Asian cities accounts for both highest water footprints of grey and blue water with an average footprint across all Asian cities estimated to 139 ± 64.6 liter per capita/yr for Bleu water, and to 248.5 ± 166.8 liters per capita/yr for Grey water. While Africa accounted for 72.78 ± 82.4 liters per capita/yr for Bleu water and to 60 ± 35 liters per capita/yr for Grey water, and Latin America 23 ± 4.6 liters per capita for Blue water and 26.7 ± 4.5 liters per capita/yr for Grey water. Surprisingly, although that Latin America (8,520 US$) have the highest income per capita then Asia (5,635 US$) and Africa (1,809 US$) (World Bank, 2022), their water footprints seems to be less flattened; nevertheless, water footprint is correlated to expenditures (Wiedmann et al., 2020), the more you spend you the higher your water footprint gets (Hachaichi and Baouni, 2020); hence, we highly believe that this issue is related the sample size took from Latin America (33 cities), compared to Asia and Africa which hare represented by 71 cities each (see electronic supplementary information file for further details).

Chart, box and whisker chart

Description automatically generated

**Figure 4:** Distribution of virtual water across selected cities of the Global South by continent (Africa, Asia, and Latin America).

Results (Fig.3 and 4) for the Blue water category shows that Asian and North African cities are the among the highest Global Southern cities that imports fresh water from the global economic market. For Asia, three Chinese cities have the highest quantities of imported water embedded within goods and services namely Beijing with 328.45 liters per capita/yr, followed by Guangdong with 267.42 liters per capita/yr, and Jiangsu with 248 liters per capita/yr. From North African region, we find Tunis (Tunisia) is associated with 314.65 liters per capita/yr, while Casablanca, Tangier and Laayoun (Morocco) are associated with the respected total embedded fresh water of 301.1, 285.6, and 251.65 liters per capita/yr. North Africa is considered a climate change hot spots (Diffenbaugh and Giorgi, 2012; Schmitz et al., 2013) with a strong temperature increase (Nashwan et al., 2019; Zeroual et al., 2019) and high drought risks (Hertig and Jacobeit, 2008), particularly there are greater climate vulnerabilities in term of water resources (Lionello and Scarascia, 2018; Tramblay et al., 2018) in Algeria, Egypt, Libya, Morocco, and Tunisia as highlighted by (Schilling et al., 2020) with major social implication (given the fact that all North African countries -except Algeria- are dependent on agriculture as the primary input for GDP and particularly employment, and any fluctuations may lead to social instability and most likely encourage climate immigration towards Europe). The combination of climate change and rapid population expansion in North Africa is extremely likely to exacerbate the already precarious water situation (Haddadin, 2001) paling countries belonging to this region among the highest countries with the highest Hydrological Water Stress Index (HWSI) and Social Water Scarcity Index (SWSI); therefore, this may explain why Norther African cities are purchasing goods and services from the global economic market with high embedded water quantities.

We know that the rainfall is projected to decrease (according to CMIP5 from the GCM) by -10% to -20% for large parts in North Africa (IPCC, 2013) while (Droogers et al., 2012) by simulating future water resources (until 2050) found that the region will decrease in water supply by -12% and an increase in water demand by +50%. This projections are confirmed via different approached namely by Global Climate Models (GCMs) as in (Collins et al., 2013), Regional Climate Models (RCMs) as in (Bucchignani et al., 2018) and statistical projections as in (Hertig and Jacobeit, 2008). However, it is important to highlight that human activities have had a far greater impact on North African aquifers than climate variability (Leduc et al., 2017; Lezzaik and Milewski, 2018), overexploitation has resulted in a reduction in groundwater levels in various Maghreb subregions during the last 50 years (Treidel et al., 2011; Zkhiri et al., 2019) this has also resulted in a decrease in the quality of water in certain aquifers of the region and put a heavy burden on water availability.

On the other hand, results for the Grey water category showed that Atolls (Maldives) have the highest virtual water consumption across all the selected cities with value estimated to 667.99 liters per capita/yr, the Maldives considering it’s geographical attributes it’s facing several environmental risks among them all water availability and food insecurity (Zubair and Nijamdeen, 2022) alongside to being the 1st South Asian tourism destination the city heavily relay on the global economic market to satisfy local development, local citizens and tourists requirement. Atolls is followed by the three Chinese’ major cities such as Beijing with 622.8 liters per capita/yr. Chinese cities represent a share of the top Global Southern cities’ freshwater footprint Guangdong with 516.64 liters per capita/yr, and Tianjin with 486.80 liters per capita/yr.

****

**Figure 5:** Top 20 Global Southern cities with highest values of virtual water.

Decomposing the virtual water footprint of top 20 cities of the Global South with highest virtual water footprints (Fig.5) show uneven sectoral distribution of the virtual water footprint. For instance, Tunis (Tunisia) the “Food” sector account for 93% of the total freshwater footprint, followed by “Transport” with 3%, as stated earlier North African countries are extremely vulnerable to climate variabilities and fluctuated precipitation regimes (Prudhomme et al., 2014), and mostly their agriculture is qualified as “rain-fed” agriculture (Schilling et al., 2020); hence, North African cities tends to rely heavily on the global economic market for agriculture-related products to mitigate the impact of climate change and the local mismanagement of water resources. On the other hand, the sector of “Services” represents the bulk of the virtual water footprint for the city of Atolls (Maldives) by a share estimated to 70%, followed by “Food” sector with a footprint estimated to 10%. Not surprisingly, Maldives is a pure touristic country, and therefore it imports most of its touristic services, worldwide.

Considering the Grey water footprint, results showed that, unlike other cities virtual water distribution, Chinese cities are causing water pollution elsewhere, and the vast majority of this pollution is allocated to the “Transport” sector whereby, for instance, in Beijing represents 41.7% of the total grey water footprint of the city knowing that China detains the highest share (33.5%) of owning German (BMW) cars worldwide, followed by the USA with 13.2% (Statista, 2022), followed by “Food” with 28% knowing that China has experienced a crop failure which led to a significant rise in wheat imports, contributing to a doubling of global wheat prices (Sternberg, 2012), and “Energy” sector with 22% given the fact that China is currently under a major economic development and requires energy to support its growth (Lin and Wang, 2012; Yin and Lam, 2021).

Chart

Description automatically generated

**Figure 6:** Top 20 Global Southern cities with highest values of virtual water decomposition by final major consumption categories.

Decomposing the water footprint by major final consumption categories and by income category show that almost the same sectoral decomposition

Chart, bar chart

Description automatically generated

**Figure 7:** Global South’s virtual water decomposition by major consumption categories.

Decomposing the water footprint by major final consumption categories show that

Chart, bar chart

Description automatically generated

**Figure 8:** Global South’s virtual water decomposition by major consumption categories and by continent.

Decomposing the water footprint by major final consumption categories show that

Chart

Description automatically generated

**Figure 9:** Global South’s virtual water decomposition by industrial sectors and income classes.

Overall, we found that North African regions are importing goods and services from different countries which can provide a resilient approach to buffers climate change at the local scale. Add count of countries targeted by each country (table maybe!)

**Add maps here**

* 1. **Virtual water policy: Hotspots and architectures of handicaps**

Water is not only a unique problem, but instead it is a part of a holistic complex system denoted Water-Food-Energy nexus. Therefore, actions that are placed on water are also affecting the other two sub-systems (energy and food).

Virtual water in the “Food” category include those from electricity generation, solid waste treatment,

Virtual water from “transport” category include the production and maintenance of private cars

The Australian Industry Group (AIG) further discusses

**Energy**

1. **Conclusion**

Water is not unequally distributed across countries and regions, and its availability is highly dependent on the future pathways of Earth’s climate system. Moreover, most of the water humanity is currently consuming is invisible by nature. It is embedded within goods and services purchased from the global economic market. Hence, it is also vital to be prepared to manage the virtual part of water while making fundamental decisions or evaluating future choices and strategies.

Cities of the Global South can import goods and services that require massive water input from the global economic market in order to amortize the current and future climate impacts on the local water sources.

1. **References**

Bucchignani, E., Mercogliano, P., Panitz, H.-J., Montesarchio, M., 2018. Climate change projections for the Middle East–North Africa domain with COSMO-CLM at different spatial resolutions. Advances in Climate Change Research, Including special topic on China Energy Modeling Forum 9, 66–80. https://doi.org/10.1016/j.accre.2018.01.004

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W.J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver, A.J., Wehner, M.F., Allen, M.R., Andrews, T., Beyerle, U., Bitz, C.M., Bony, S., Booth, B.B.B., 2013. Long-term Climate Change: Projections, Commitments and Irreversibility. Climate Change 2013 - The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 1029–1136.

Cook, B.I., Anchukaitis, K.J., Touchan, R., Meko, D.M., Cook, E.R., 2016. Spatiotemporal drought variability in the Mediterranean over the last 900 years. Journal of Geophysical Research: Atmospheres 121, 2060–2074. https://doi.org/10.1002/2015JD023929

Diffenbaugh, N.S., Giorgi, F., 2012. Climate change hotspots in the CMIP5 global climate model ensemble. Climatic Change 114, 813–822. https://doi.org/10.1007/s10584-012-0570-x

Droogers, P., Immerzeel, W.W., Terink, W., Hoogeveen, J., Bierkens, M.F.P., van Beek, L.P.H., Debele, B., 2012. Water resources trends in Middle East and North Africa towards 2050. Hydrology and Earth System Sciences 16, 3101–3114. https://doi.org/10.5194/hess-16-3101-2012

Fu, T., Xu, C., Yang, L., Hou, S., Xia, Q., 2022. Measurement and driving factors of grey water footprint efficiency in Yangtze River Basin. Science of The Total Environment 802, 149587. https://doi.org/10.1016/j.scitotenv.2021.149587

Haberl, H., Wiedenhofer, D., Pauliuk, S., Krausmann, F., Müller, D.B., Fischer-Kowalski, M., 2019. Contributions of sociometabolic research to sustainability science. Nat Sustain 2, 173–184. https://doi.org/10.1038/s41893-019-0225-2

Hachaichi, M., Baouni, T., 2021. Virtual carbon emissions in the big cities of middle-income countries. Urban Climate 40, 100986. https://doi.org/10.1016/j.uclim.2021.100986

Hachaichi, M., Baouni, T., 2020. Downscaling the planetary boundaries (Pbs) framework to city scale-level: De-risking MENA region’s environment future. Environmental and Sustainability Indicators 5, 100023. https://doi.org/10.1016/j.indic.2020.100023

Haddadin, M.J., 2001. Water Scarcity Impacts and Potential Conflicts in the MENA Region. Water International 26, 460–470. https://doi.org/10.1080/02508060108686947

Harmanny, K.S., Malek, Ž., 2019. Adaptations in irrigated agriculture in the Mediterranean region: an overview and spatial analysis of implemented strategies. Reg Environ Change 19, 1401–1416. https://doi.org/10.1007/s10113-019-01494-8

Hertig, E., Jacobeit, J., 2008. Downscaling future climate change: Temperature scenarios for the Mediterranean area. Global and Planetary Change, Mediterranean climate: trends, variability and change 63, 127–131. https://doi.org/10.1016/j.gloplacha.2007.09.003

Hoekstra, A.Y., Mekonnen, M.M., 2012. The water footprint of humanity. Proceedings of the National Academy of Sciences 109, 3232–3237. https://doi.org/10.1073/pnas.1109936109

IPCC, I., 2013. I: Atlas of global and regional climate projections. Climate change.

Kitzes, J., 2013. An Introduction to Environmentally-Extended Input-Output Analysis. Resources 2, 489–503. https://doi.org/10.3390/resources2040489

Leduc, C., Pulido-Bosch, A., Remini, B., 2017. Anthropization of groundwater resources in the Mediterranean region: processes and challenges. Hydrogeol J 25, 1529–1547. https://doi.org/10.1007/s10040-017-1572-6

Lelieveld, J., Proestos, Y., Hadjinicolaou, P., Tanarhte, M., Tyrlis, E., Zittis, G., 2016. Strongly increasing heat extremes in the Middle East and North Africa (MENA) in the 21st century. Climatic Change 137, 245–260. https://doi.org/10.1007/s10584-016-1665-6

Lenzen, M., Foran, B., 2001. An input–output analysis of Australian water usage. Water Policy 3, 321–340. https://doi.org/10.1016/S1366-7017(01)00072-1

Lenzen, M., Kanemoto, K., Moran, D., Geschke, A., 2012. Mapping the structure of the world economy. Environmental science & technology 46, 8374–8381.

Lenzen, M., Moran, D., Kanemoto, K., Geschke, A., 2013. Building Eora: a global multi-region input–output database at high country and sector resolution. Economic Systems Research 25, 20–49.

Leontief, W., 1986. Input-Output Economics. Oxford University Press.

Lezzaik, K., Milewski, A., 2018. A quantitative assessment of groundwater resources in the Middle East and North Africa region. Hydrogeol J 26, 251–266. https://doi.org/10.1007/s10040-017-1646-5

Lin, B., Wang, T., 2012. Forecasting natural gas supply in China: Production peak and import trends. Energy Policy, Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy 49, 225–233. https://doi.org/10.1016/j.enpol.2012.05.074

Lionello, P., Scarascia, L., 2018. The relation between climate change in the Mediterranean region and global warming. Reg Environ Change 18, 1481–1493. https://doi.org/10.1007/s10113-018-1290-1

Miller, R.E., Blair, P.D., 2009. Input-Output Analysis: Foundations and Extensions. Cambridge University Press.

Nashwan, M.S., Shahid, S., Abd Rahim, N., 2019. Unidirectional trends in annual and seasonal climate and extremes in Egypt. Theor Appl Climatol 136, 457–473. https://doi.org/10.1007/s00704-018-2498-1

Pichler, P.-P., Jaccard, I.S., Weisz, U., Weisz, H., 2019. International comparison of health care carbon footprints. Environ. Res. Lett. 14, 064004. https://doi.org/10.1088/1748-9326/ab19e1

Pichler, P.-P., Zwickel, T., Chavez, A., Kretschmer, T., Seddon, J., Weisz, H., 2017. Reducing Urban Greenhouse Gas Footprints. Sci Rep 7, 14659. https://doi.org/10.1038/s41598-017-15303-x

Prudhomme, C., Giuntoli, I., Robinson, E.L., Clark, D.B., Arnell, N.W., Dankers, R., Fekete, B.M., Franssen, W., Gerten, D., Gosling, S.N., Hagemann, S., Hannah, D.M., Kim, H., Masaki, Y., Satoh, Y., Stacke, T., Wada, Y., Wisser, D., 2014. Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment. Proceedings of the National Academy of Sciences 111, 3262–3267. https://doi.org/10.1073/pnas.1222473110

Raa, T. ten, 2006. The Economics of Input-Output Analysis. Cambridge University Press.

Raa, T.T., 2007. The Extraction of Technical Coefficients from Input and Output Data. Economic Systems Research 19, 453–459. https://doi.org/10.1080/09535310701698597

Schilling, J., Hertig, E., Tramblay, Y., Scheffran, J., 2020. Climate change vulnerability, water resources and social implications in North Africa. Reg Environ Change 20, 15. https://doi.org/10.1007/s10113-020-01597-7

Schmitz, C., Lotze-Campen, H., Gerten, D., Dietrich, J.P., Bodirsky, B., Biewald, A., Popp, A., 2013. Blue water scarcity and the economic impacts of future agricultural trade and demand. Water Resources Research 49, 3601–3617. https://doi.org/10.1002/wrcr.20188

Souissi, A., Mtimet, N., McCann, L., Chebil, A., Thabet, C., 2022. Determinants of Food Consumption Water Footprint in the MENA Region: The Case of Tunisia. Sustainability 14, 1539. https://doi.org/10.3390/su14031539

Statista, 2022. Key automobile markets of BMW Group 2020 [WWW Document]. Statista. URL https://www.statista.com/statistics/267252/key-automobile-markets-of-bmw-group/ (accessed 3.12.22).

Sternberg, T., 2012. Chinese drought, bread and the Arab Spring. Applied Geography 34, 519–524. https://doi.org/10.1016/j.apgeog.2012.02.004

Tramblay, Y., Jarlan, L., Hanich, L., Somot, S., 2018. Future Scenarios of Surface Water Resources Availability in North African Dams. Water Resour Manage 32, 1291–1306. https://doi.org/10.1007/s11269-017-1870-8

Treidel, H., Martin-Bordes, J.L., Gurdak, J.J., 2011. Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations. CRC Press.

Weinzettel, J., Hertwich, E.G., Peters, G.P., Steen-Olsen, K., Galli, A., 2013. Affluence drives the global displacement of land use. Global Environmental Change 23, 433–438. https://doi.org/10.1016/j.gloenvcha.2012.12.010

Wiedmann, T., Lenzen, M., Keyßer, L.T., Steinberger, J.K., 2020. Scientists’ warning on affluence. Nat Commun 11, 3107. https://doi.org/10.1038/s41467-020-16941-y

World Bank, 2022. GDP per capita (current US$) | Data [WWW Document]. URL https://data.worldbank.org/indicator/NY.GDP.PCAP.CD (accessed 3.15.22).

World Bank, 2021. Official exchange rate (LCU per US$, period average) | Data [WWW Document]. URL https://data.worldbank.org/indicator/PA.NUS.FCRF (accessed 11.1.21).

Yin, Y., Lam, J.S.L., 2021. Energy strategies of China and their impacts on energy shipping import through the Straits of Malacca and Singapore. Maritime Business Review ahead-of-print. https://doi.org/10.1108/MABR-12-2020-0070

Zeroual, A., Assani, A.A., Meddi, M., Alkama, R., 2019. Assessment of climate change in Algeria from 1951 to 2098 using the Köppen–Geiger climate classification scheme. Clim Dyn 52, 227–243. https://doi.org/10.1007/s00382-018-4128-0

Zkhiri, W., Tramblay, Y., Hanich, L., Jarlan, L., Ruelland, D., 2019. Spatiotemporal characterization of current and future droughts in the High Atlas basins (Morocco). Theor Appl Climatol 135, 593–605. https://doi.org/10.1007/s00704-018-2388-6

Zubair, L., Nijamdeen, A., 2022. The Maldives, in: Glantz, M.H. (Ed.), El Niño Ready Nations and Disaster Risk Reduction: 19 Countries in Perspective, Disaster Studies and Management. Springer International Publishing, Cham, pp. 45–62. https://doi.org/10.1007/978-3-030-86503-0\_3