Methodology note: Water risk and global trade

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This document was written as a supplement to SEI Working Paper No. 2016-07, *Introducing the Transnational Climate Impacts Index: Indicators of country-level exposure – methodology report*. It describes in detail the approach taken to develop Indicator 8: Embedded water risk. The working paper is available at: https://www.sei-international.org/publications?pid=2970.

1. Context

Globally, agricultural production is predicted to increase in response to population and economic growth, against a backdrop of changing climatic conditions. Water availability, as a key limiting factor in crop growth, will be fundamental in determining the scope for the continuation and possible increase of production. However, as a resource often subject to intense competition and the influence of changing meteorological patterns, the future supply of water for agriculture is not uniformly guaranteed.

Nations are reliant not only of the goods and services produced territorially, but also on imported products from abroad and raw commodities that are produced and/or processed overseas. Impacts occurring due to the production of raw commodities are therefore often displaced from the point of final consumption. These “embedded” or “virtual” impacts that are associated with consumption, including those linked to the use of water, are typically estimated using life-cycle analyses such as input-output (IO) modelling, where environmental impacts are associated with specific production system outputs which are then traced along supply chains to the consumer. SEI’s IOTA (Input-Output Trade Analysis) model is an example of such a tool where the environmental impacts of consumption can be analysed, with the integration of physical production and trade data facilitating analysis of production impacts at the level of individual agricultural commodities.

In the context of estimating the water-related impacts associated with consumption, the Water Footprint, of which the main proponent is the Water Footprint Network, offers the most widely recognized indicator. However, commonly, this indicator is only used to report estimates of the total water used (e.g. in the production of a particular commodity, or in the supply chain of a particular end product) with no information about the location of water use. The utilization of Water Footprint data within the IOTA model – as conducted, for example, in West et al. (2013) – allows for the assessment of water use for country-level production on a per-commodity basis. However, this output on its own is insufficient for assessing the relative risk associated with this water use, because it contains no information on: a) the local context of withdrawal at catchment scale, where water availability may be spatially and temporally variable, and b) competition for this water, which may determine water scarcity, and therefore risk to production systems.

Unfortunately, as highlighted within recent analysis as part of the Measure What Matters project, readily available information on water availability and competition at useful spatial, and particularly temporal, resolution is generally of poor quality, inconsistent or unavailable.[1] Despite this, various attempts have been made to use combinations of data to estimate water availability and scarcity at relevant scales. One example is the World Resources Institute's *Aqueduct* database, which estimates – among other things – "Baseline Water Stress" at basin scale using estimates of total water withdrawal and water availability.[2]

Within the Adaptation Without Borders project, the Aqueduct data was used with SEI's IOTA model to produce a national-level indicator of relative water risk associated with the consumption of individual agricultural commodities embedded within international supply chains. As a pilot study, which still relies on national-level aggregated production and water information, the outputs from the work do not fully overcome current consumption-based water indicator limitations, but act to highlight the potential for water availability to be an important risk factor in the context of climate change. Importantly, this risk may depend on the relative reliance on international supply chains and individual locations of commodity production, the nature of which may vary among consuming countries. Further work to improve the model and environmental extensions used in this pilot has great potential to increase the power of this analysis to assess climate-driven risks to consumption, and therefore national economies.

2. Methods

The production of a consumption-based water risk indicator is reliant on three methodological components: a) a method to link production of agricultural commodities to final consumers via international supply chains, b) a method to estimate country-level water risk, and c) a method to link water risk profiles to the modelled trade system.

a) The IOTA hybrid MRIO model

The IOTA model is a hybridized physical-financial multi-regional input-output (MRIO) model. The financial MRIO tables which underlie the model are sourced from the Global Trade Analysis Project (GTAP) and represent the entire global economy by describing monetary flows between 57 industrial sectors across 129 global regions. The presence of this data allows for the analysis of supply chain pathways across the global economy: the financial MRIO data is transformed to represent the economic outputs required to meet final demand. Physical input data for the IOTA model takes the form of production and bilateral trade data, sourced from FAO. Production data describes the physical quantities of commodity production at the country level. Bilateral trade data is combined (algorithmically to deal with data inconsistencies) with this production data to describe the transport of primary commodities from country of production to their traded destination. The physical production and bilateral trade data is then joined to the transformed financial data. Thereafter, rather than the model detailing financial outputs from different economic sectors, it outputs the physical quantity of production of primary commodities necessary to fulfil final demand.

In summary, the model is able to allocate production of raw agricultural commodities to the point of final consumption, and thereby allows the total consumption by a region or group of regions to be analysed to estimate the total quantities of embedded materials associated with this consumption. Additionally, information about the location of production is retained, as is information about from which sector/regional economy the final purchase was made that drives primary commodity production. Environmental data associated with production can then be

[1] See http://measurewhatmatters.info/wp-content/uploads/2014/09/MWM-Water-Discussion-Paper-September-20142.pdf.

[2] Details of the methods and data sources used to produce these metrics are available at: http://www.wri.org/our-work/project/aqueduct/methodology.

incorporated to provide information about potential impacts associated with production. In standard IOTA outputs, this environmental data includes crop and country-specific land areas utilized for production (sourced from FAOStat) and water use estimates sourced from the Water Footprint Network (WFN). Thus, for example, estimates can be made of the water use required in the production of soybean in Brazil which is driven by the consumption of goods and services in Sweden.

b) Country-level water scarcity

While the baseline IOTA output contains estimates of water use associated with crops, it says nothing about the context of this water use in terms of the relative risk to the available water supply. Therefore, for the purposes of this pilot, a suite of basic country-level water risk indicators was developed based on the data contained within WRI's *Aqueduct* database. *Aqueduct* contains data estimates for sub-country basins on water withdrawal and water availability. Within the Aqueduct maps these are used to create Baseline Water Stress (BWS) estimates by first dividing withdrawal by availability, and then undergoing a normalization process to scale outputs to a value between 0 and 5. Values greater or equal to 3 are defined as being subject to Medium Water Stress or above. A further classification, "Arid", is also specified where both withdrawal and availability of water are very low. Because IOTA production outputs are currently only available at national scale, country-level water stress indices were determined from the sub-country *Aqueduct* data.[3] Each basin within the Aqueduct dataset is tagged with an associated country which facilitates this process. Two indicators have been developed to explore water stress at country level:

1. Baseline Water Stress at aggregate country level:

For each country within the *Aqueduct* data set, total water withdrawal and total blue water availability are calculated by summing across all basin-level data. A national-level BWS was then calculated by dividing total water withdrawal by total availability, and normalizing results to obtain a score between 1 and 5.

2. Land area subject to Baseline Water Stress:

For each country, the total land area is divided proportionally into those falling into the different BWS categories (1 to 5, plus "arid"). The proportion of land area within each country that has a BWS score of 3 or greater (plus "arid") is then calculated, with values closer to 1 indicating relatively higher water stress.

It should be noted that these two indicators often give contrasting results. For example, it is possible for total water withdrawal at national level to be significantly lower than total availability (and therefore score 1 on the first indicator), but for a large proportion of total land area within a country to be subject to water stress. Egypt is a good example: it scores 1 on the first indicator but 0.81 in the second, due to the fact that 97% of water withdrawal takes place within sources classified as "1. Low" (principally those associated with the Nile), but these only account for 19% of total land area within the country. Therefore, Egypt could be classified as both low and high risk, depending on the perspective adopted.

c) Linking risk to consumption

Output from the IOTA model details the location and total amount of production taking place to fulfil final demand. For each country, from part b), we also have an estimate of relative

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[3] Ideally, information would be retained at the sub-country/basin level provided in Aqueduct, which should be possible using methodological improvements detailed in Section 5.

scarcity. Depending on the nature of the indicator used, a risk threshold is defined. In the case of Indicator 1, we define this threshold as those countries with a national-level BWS score of 3 or more. In the case of Indicator 2, we define this threshold as those countries where more than 50% of the total countries' land is subject to a BWS score of 3 or more. We also create a variant of each indicator where countries are only defined as high risk when data suggests irrigation of the commodity of interest also takes place.[4] For each of these indicators, from the perspective of a consuming country it is therefore possible to calculate the proportion of commodity production embedded within supply chains that is sourced from a country of high water risk.

3. Example output

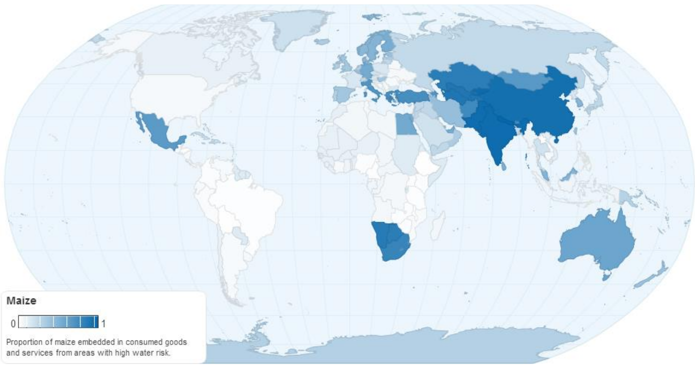

Figure 1. The proportion of maize production embedded within the consumption of countries which is sourced from areas of high water risk (defined using Indicator 2 (irrigated), with high risk defined as production in a country with more than 50% of land area having a BWS of 3 or more).

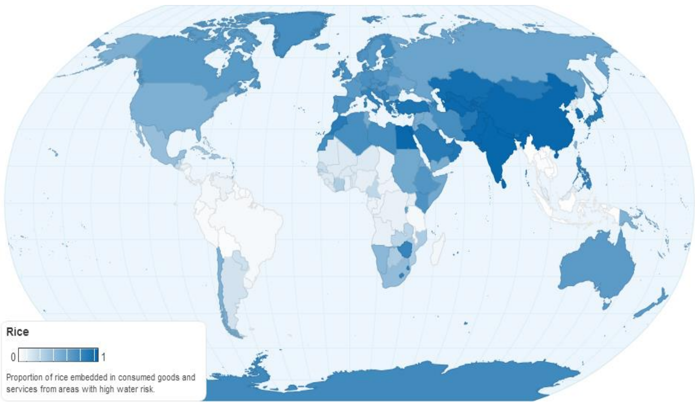

Figure 2. The proportion of rice production embedded within the consumption of countries which is sourced from areas of high water risk (defined using Indicator 2 (irrigated), with high risk defined as production in a country with more than 50% of land area having a BWS of 3 or more).

Figure 1 shows, from the consuming countries' perspective, the proportion of total production of maize sourced from high risk areas (using Indicator 2 (irrigated)). Consumption within south and central Asia, Mexico, and southern Africa appears to have a high reliance on embedded maize produced in countries with high levels of water scarcity. Consumption in Europe is subject to intermediate levels of risk, and South American consumption generally appears to be associated with low levels of risk.

Figure 2 shows equivalent information for rice. In comparison to maize, risk is relatively increased across North America, Europe and northern and eastern Africa, reflecting the contrasting production locations and supply chains of maize and rice. Central and south Asia retains the highest level of consumption-based water risk.

[4] Defined by the presence of an estimate of Blue Water use (from the Water Footprint Network) for the associated commodity and country of production. The exclusion of countries where production takes place using only Green (i.e. rain) water places emphasis on the closer link between use of irrigation and freshwater scarcity.

4. Future work

The work conducted here within the scope of the Adaptation Without Borders project highlights the need, within the broader context of climate resilience, to consider extra-national climate change-related risks that may be associated with a reliance on imported and embedded commodities. In this case, an approach has been adopted to account for risks associated with water use embedded in consumption using readily-available third-party information and an existing SEI methodology (IOTA). In future, there is potential for this work to be extended to broaden the scope and relevance of risk indicators that are associated with trade and consumption patterns. This may include:

- Correlation of areas of commodity production at a sub-country level[5] with basin level water scarcity information (such as that available within Aqueduct) to ensure that risk is associated with regions of commodity production rather than national-level averages which include both arable and non-arable areas.
- Incorporation of sub-national production and trade information (such as that available via integration of the SEI-PCS model) to improve the linkage of locally-defined production information to global supply chains and therefore increase the resolution of trade pathways (and associated environmental impacts/risks) within the model.
- Inclusion of more agricultural (and addition of non-agricultural) commodities to provide an analysis of national risk associated with a more complete portfolio of production (rather than individual commodities) and of the potential competition for water between production systems.
- Extension of risk indicators beyond freshwater scarcity to, for example, groundwater scarcity, flood likelihood, drought severity, and seasonal and inter-annual variability, which may all be components of agricultural yield reductions.
- Use of structural decomposition analyses to determine the supply chain paths (i.e. the intermediate stages and locations of processing of commodities along supply chains) associated with highest levels of risk, which could be important in determining leverage points to minimise future reliance on commodities from high risk areas.
- Development of time-series to analyse potential changes in risk over time that may be associated with evolving and emerging supply chains.

[5] Sourced, for example, from http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html.