TRADE OF ECONOMICALLY AND PHYSICALLY SCARCE VIRTUAL WATER IN THE GLOBAL FOOD NETWORK

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VIRTUAL WATER TRADE

Virtual water trade (VWT): volume of water that is used for the production of goods that are subsequently traded on the international market.

The trade of agricultural products accounts for about 90% of the all virtual water (VW) displaced for human consumption (D'Odorico et al. 2019).

The VW associated to traded food at the global level is approximately 25% of the total amount of water utilized for agriculture (D'Odorico et al. 2019).

Overtime the quantity of food exchanged on international markets has increased almost three times faster than food production ('90s – 2014: Traverso and Schiavo 2020)

The amount of virtual water trade has doubled from 1986 and 2007 (Dalin et al. 2012).

Globalization, long value chains:

=> the economic and environmental system tends always more to a detachment of resource consumption from the place of resource use for production (Dorninger et al. 2021).

=> increase of interconnections and vulnerability (Tamea et al. 2016, Distefano et al. 2018, D'Odorico et al. 2019).

Through the outflow of virtual water embedded in food exports, countries renounce to precious domestic water resources, while through the inflow of VW included in food imports, countries benefit of water belonging to other areas of the world.

Rich literature on VWT:

-reconstruction and the study of the topology of the VW network worldwide (Dalin et al. 2012, Tuninetti et al. 2017),

-VW trade compensates or not for lack of water in given countries (that brings low food production) ?

- Are VW fluxes associated to agricultural products 'sustainable' from an environmental point of view ? Different estimates of water stress due to VW trade (Hoekstra and Mekonnen 2016, Soligno et al. 2019, Wiedmann and Lenzen 2018, Tuninetti et al. 2019, Rosa et al . 2019).

However, only physical water availability is typically considered when the water endowment of a country is assessed.

An important pillar for productive water use is an infrastructural, economic and institutional environment that allows water access and utilization. =>

Economic water scarcity (EWS): lack of possibilities for water utilization due to social, economic and institutional factors (Sullivan 2002, Molle and Mollinga 2003, Molden 2007).

Only recent attemps of EWS measurement at global scale and links to agriculture (Vallino et al. 2020, Rosa et al. 2020).

In this paper we reassess the VW volumes associated to the international trade of primary crops under the lens of a weight represented by both physical and economical water scarcity of the country of origin.

Novelty:

-a new viewpoint for the consideration of water scarcity is adopted;

-a quantitative measure of the VW flows that are considered scarce under this new perspective.

A COMPOSITE WATER SCARCITY INDEX (CWSI)

*CWSI = EWS * PWS*

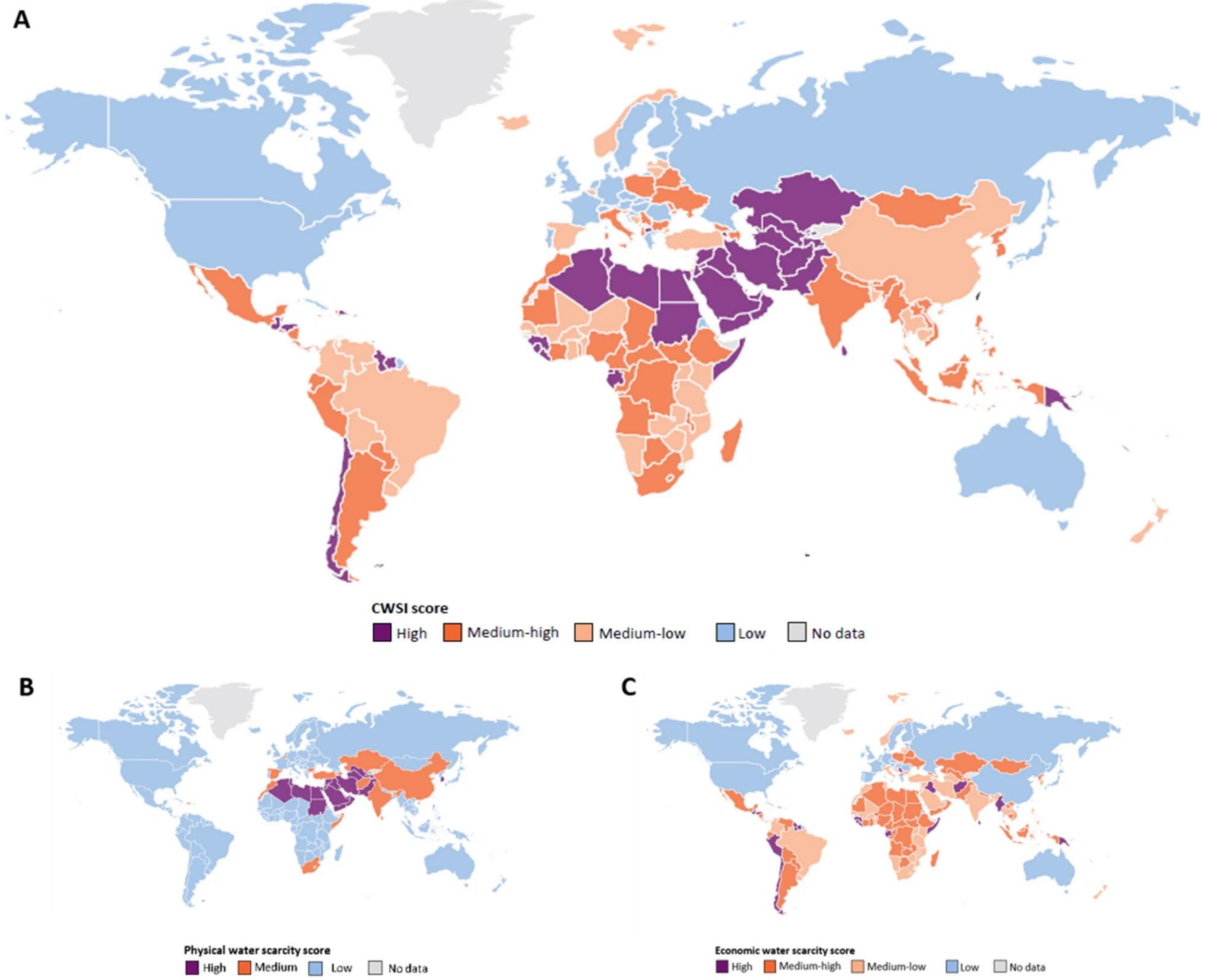
where

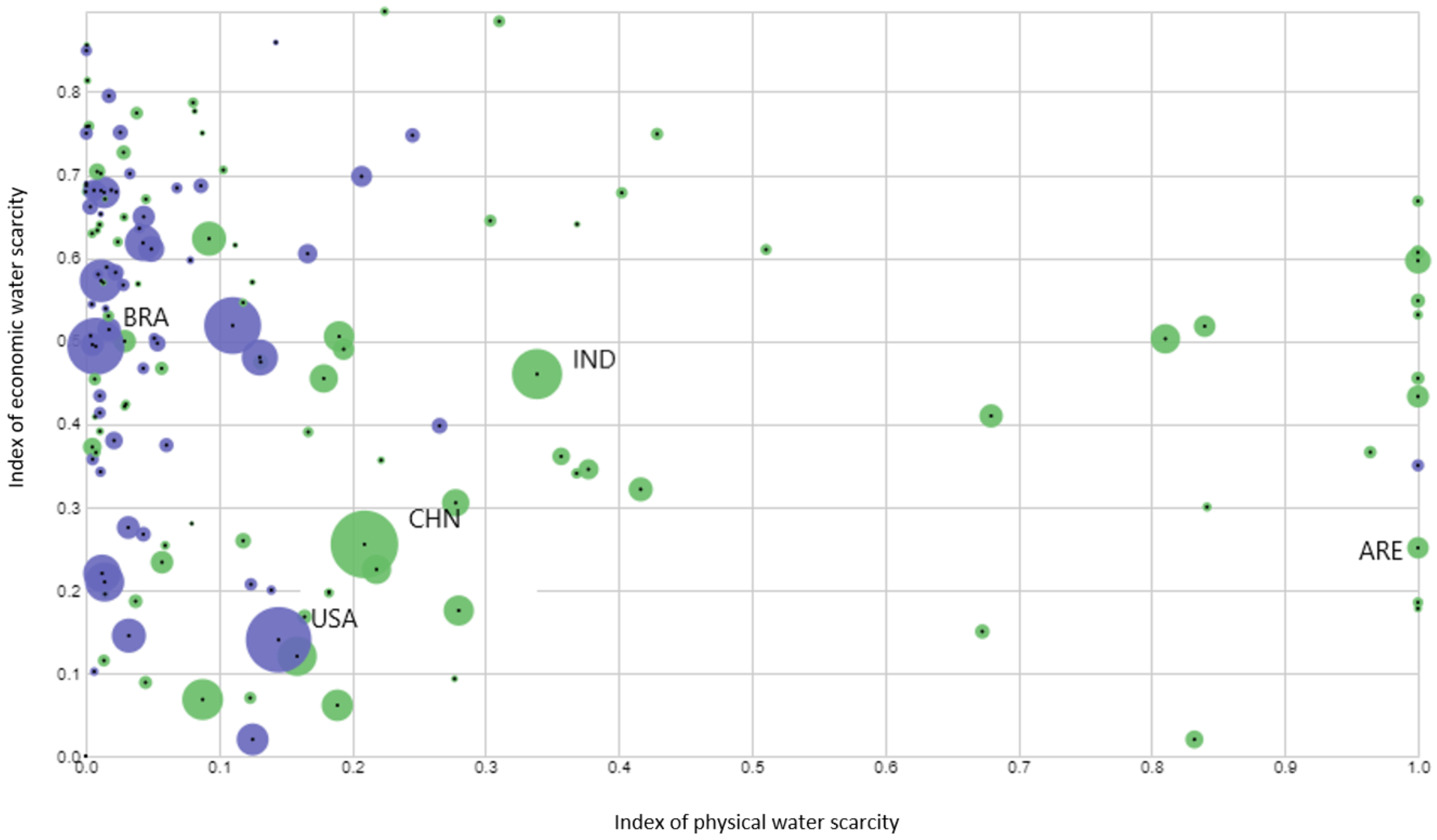
EWS (economic water scarcity) = 1-IWRM

- *IWRM = Integrated Water Resource Management (SDG indicator 6.5.1)*

PWS (physical water scarcity) = % of freshwater withdrawal over the total renewable water resources (ACQUASTAT - FAO)

Range 0-1


A
CWSI score
High
Medium-high
Medium-low
Low
No data
B
Physical water scarcity score
High
Medium
Low
No data
C
Economic water scarcity score
High
Medium-high
Medium-low
Low
No data



Physical water scarcity (hydrological pressure) and economic water scarcity (1-IWRM) for 149 countries (2017). The size of the point is proportional to the total volumes of VW involved in both export and import for that country (m3). Green points indicate net importer countries, while violet points indicate net exporter countries.

VIRTUAL WATER FLOWS BETWEEN COUNTRIES WITH LARGE DIFFERENCE IN COMPOSITE SCARCITY

We calculate the gap (Gap_{CWSI}) between the CWSI of the exporter country (e) and that of the importer (*i*) for all bilateral VW trade flows associated to primary crops

=> 151 countries; 22,200 VW fluxes; approximately 600 km3 of VW; 2016 – dataset Tamea et al. (2021).

$$Gap_{CWSI} = CWSI_e - CWSI_i$$

Positive gap = the exporter has a more severe composite scarcity than the importer, and *vice versa*.

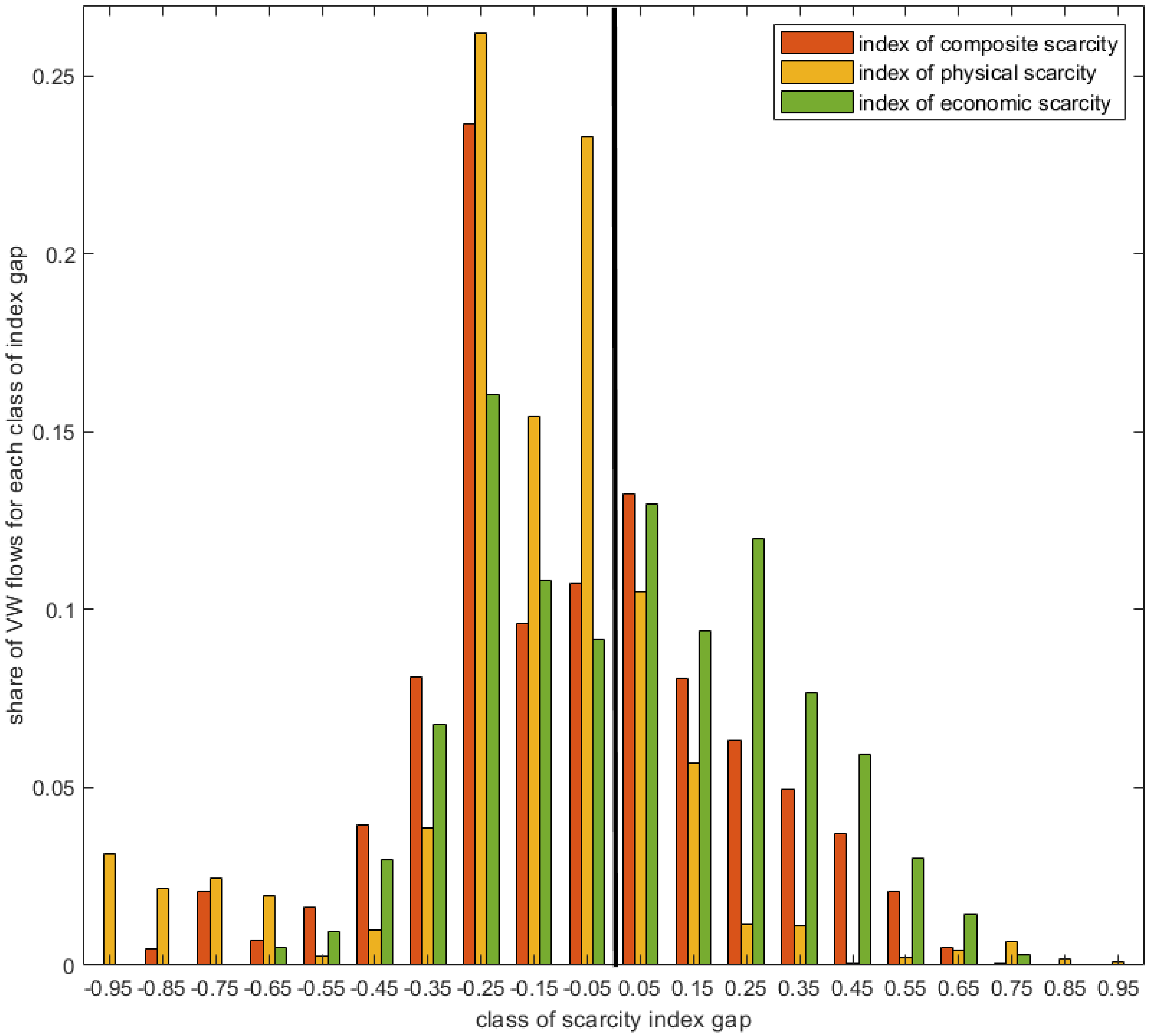
We group the index gaps in 20 classes with a width of 0.1 points each.

Share of VW flows included in each of the 20 classes, calculated over the total amount of VW trade.

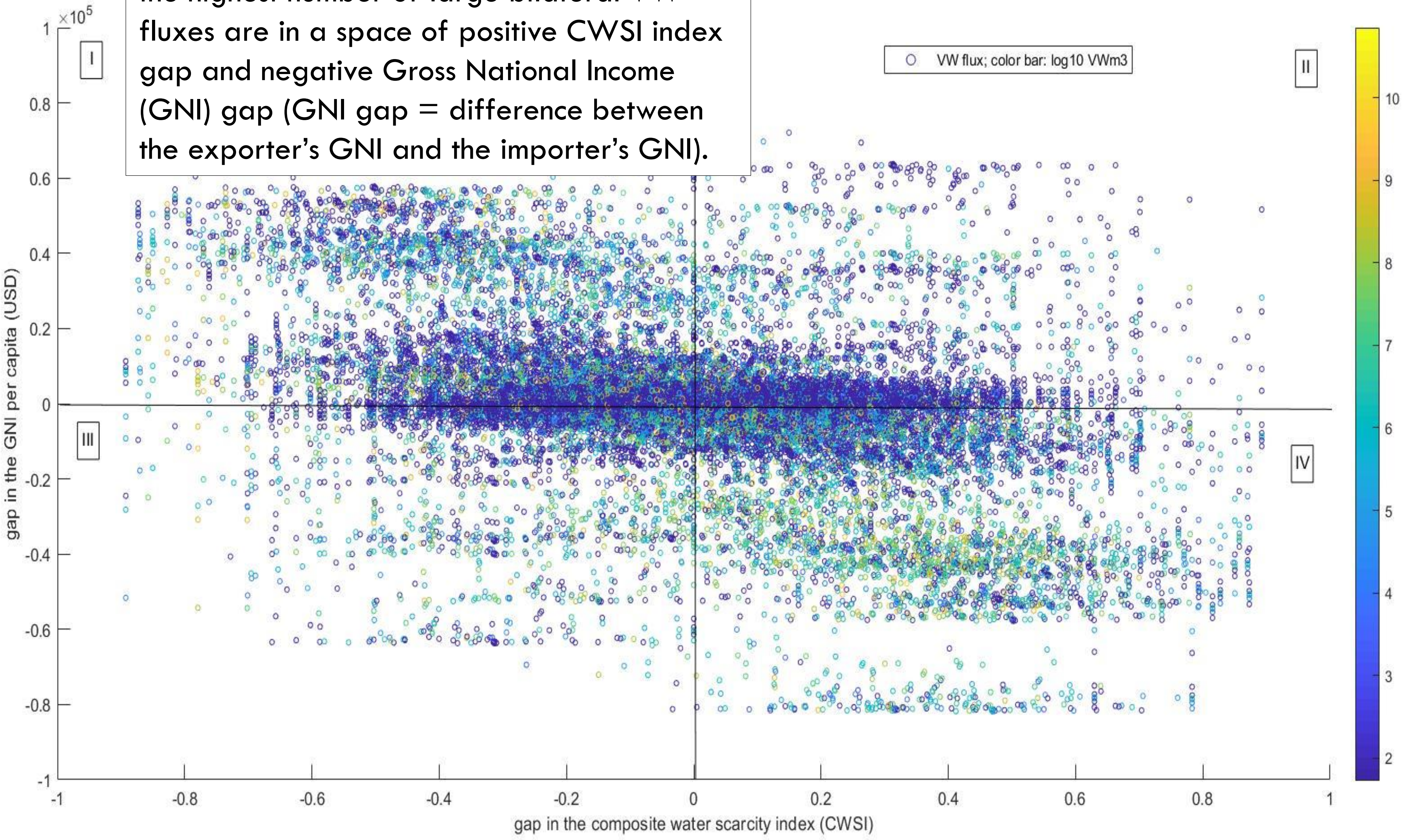
39% of exchanges of water volumes for the primary crops takes place between countries with a positive gap for composite water scarcity => unfair exchanges

6.4% of exchanges occur between countries with a large gap

53% of flows occur between countries with positive gap in economic water scarcity



the highest number of large bilateral VW fluxes are in a space of positive CWSI index gap and negative Gross National Income (GNI) gap (GNI gap = difference between the exporter's GNI and the importer's GNI).



LARGEST PLAYERS IN SCARCE VW TRADE

50 largest single VW fluxes weighted for the CWSI

Brazil to China

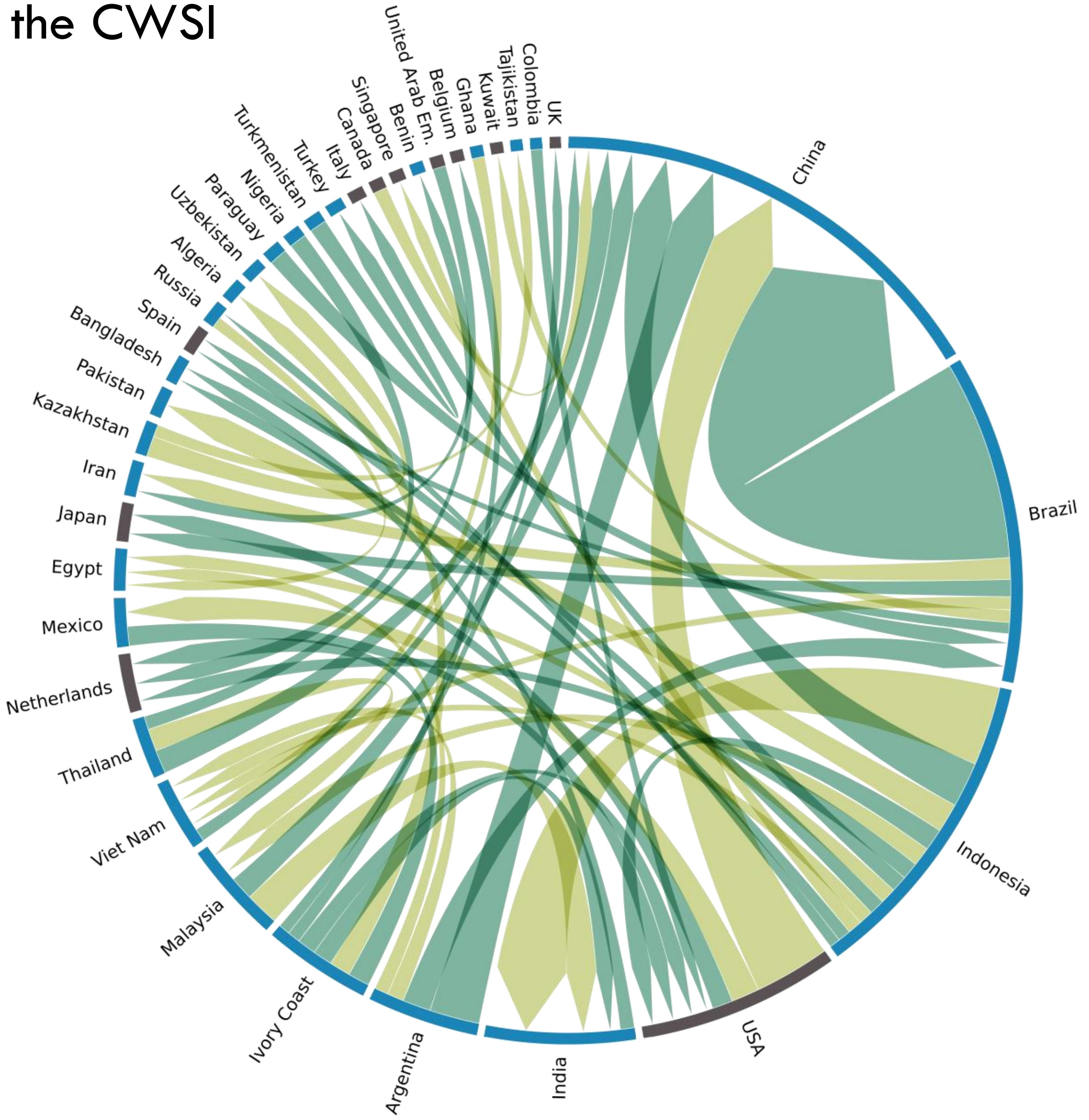
(3.5E+10 m3, 6%)

Indonesia to India

(1.39E+10 m3, 2.3%)

USA to China

(1.33E+10 m3, 2.2%)



Many unfair fluxes (dark green):
from Brazil to China, Japan, Spain
From Indonesia to China
From Ivory Coast to China, India, USA

Half of unfair fluxes: from poor to rich countries
Half of unfair fluxes: among poor countries

NET TRADE BALANCE

We analyze the balance between how much a country exports domestic scarce VW or it exploits water that is scarce for others. For each country *i (151 countries)*, we measure

scarcity-weighted VW export (WE_i) as

$$WE_i = CWSI_i * \sum_j F_{ij}$$

scarcity-weighted VW import (WI_i) as

$$WI_i = \sum_j CWSI_j F_{ji}$$

Subsequently we calculate the country's world share for volumetric export (SE_i) and import (SI_i).

Net trade

$$N_i = E_i - I_i$$

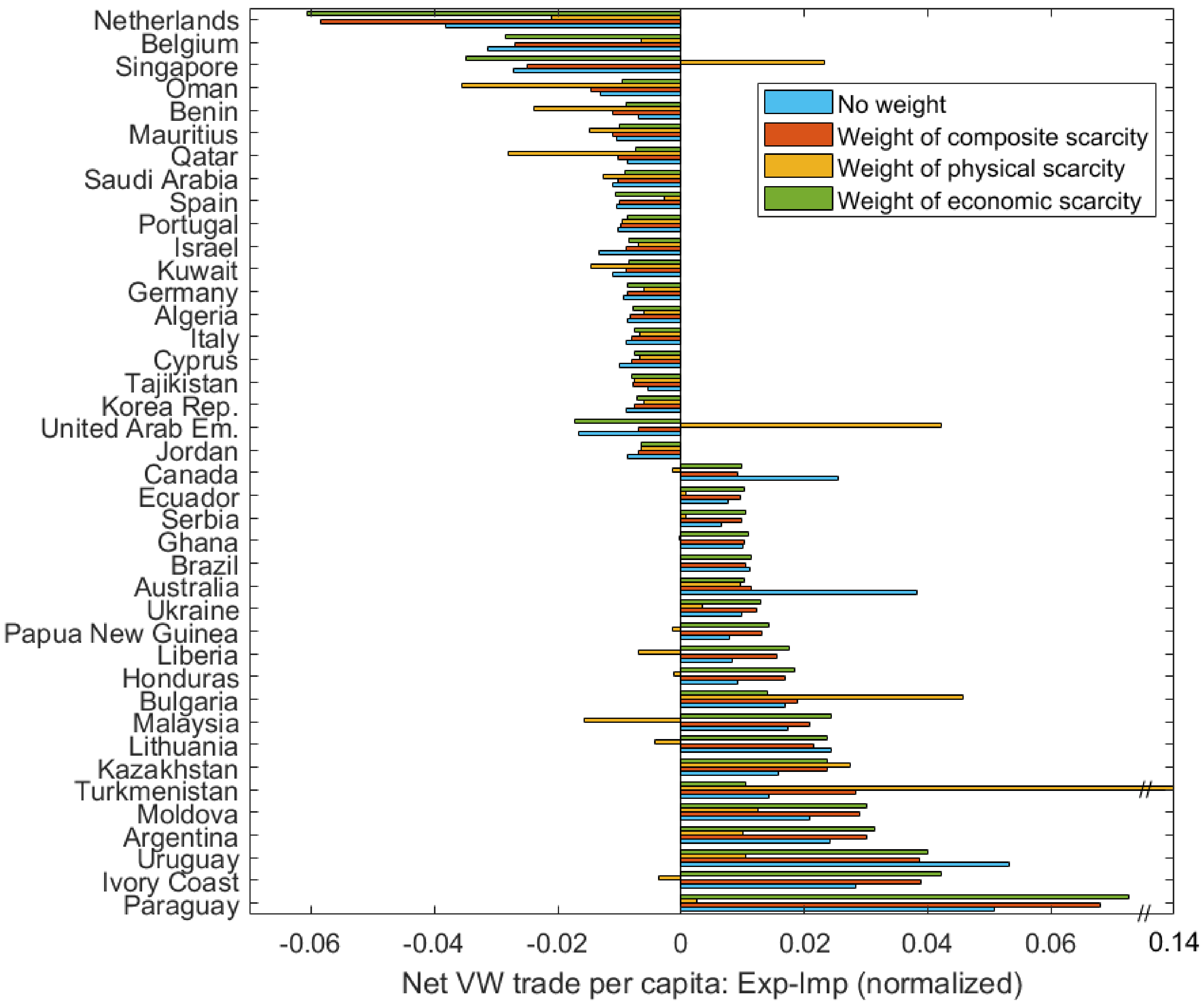
$$WN_i = WE_i - WI_i$$

CWSI | index of physical scarcity (hydrological pressure) | index of economic scarcity (1-IWRM)

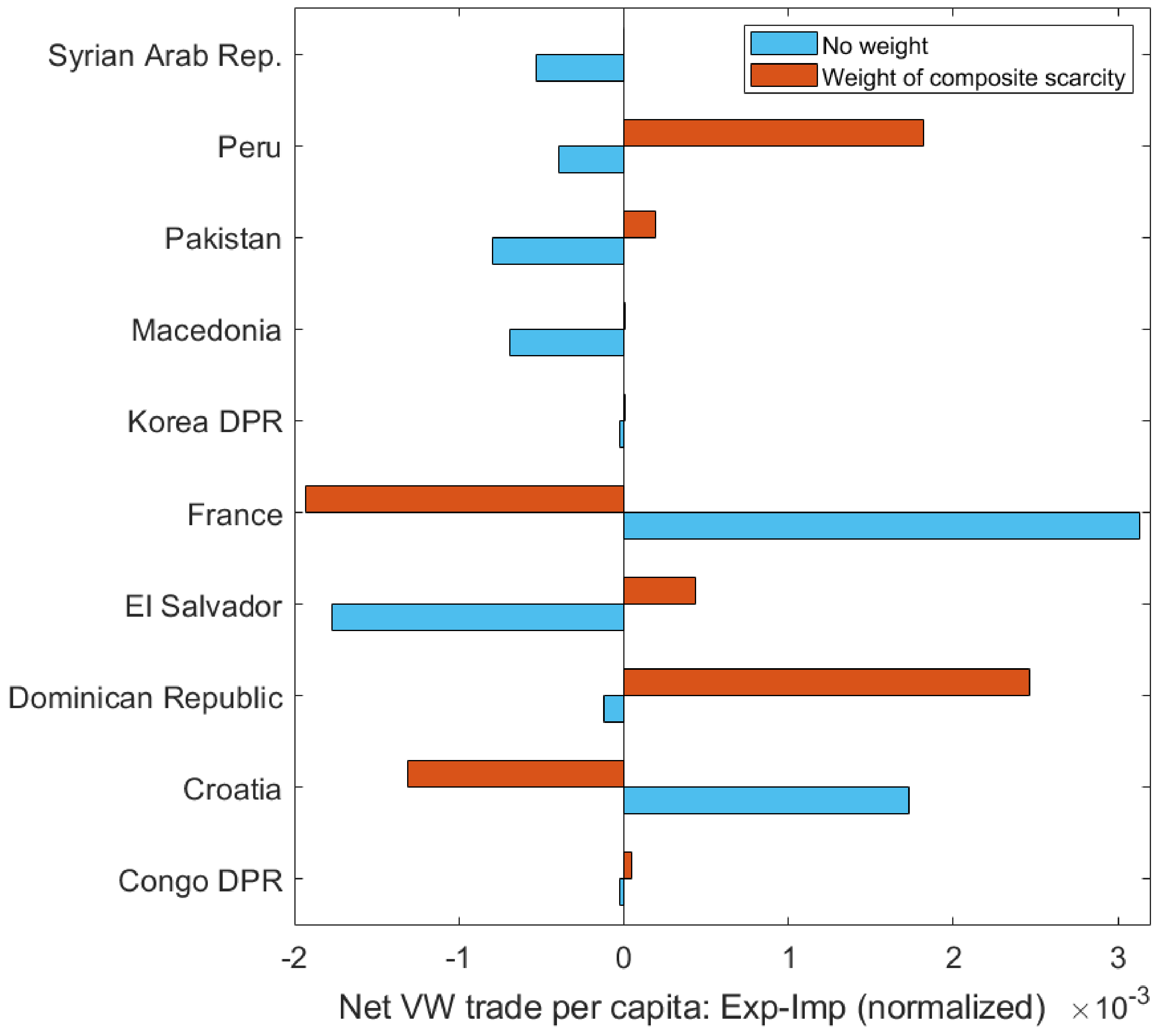
Table 1. Top 10 countries for net VW export and import, in volumetric values and weighted for the composite water scarcity index. The left layer is referred to absolute figures (*SN* and *SWN*, in percentage of the world total). The right layer is referred to per capita figures (*sn* and *swn*, in percentage of the world total).

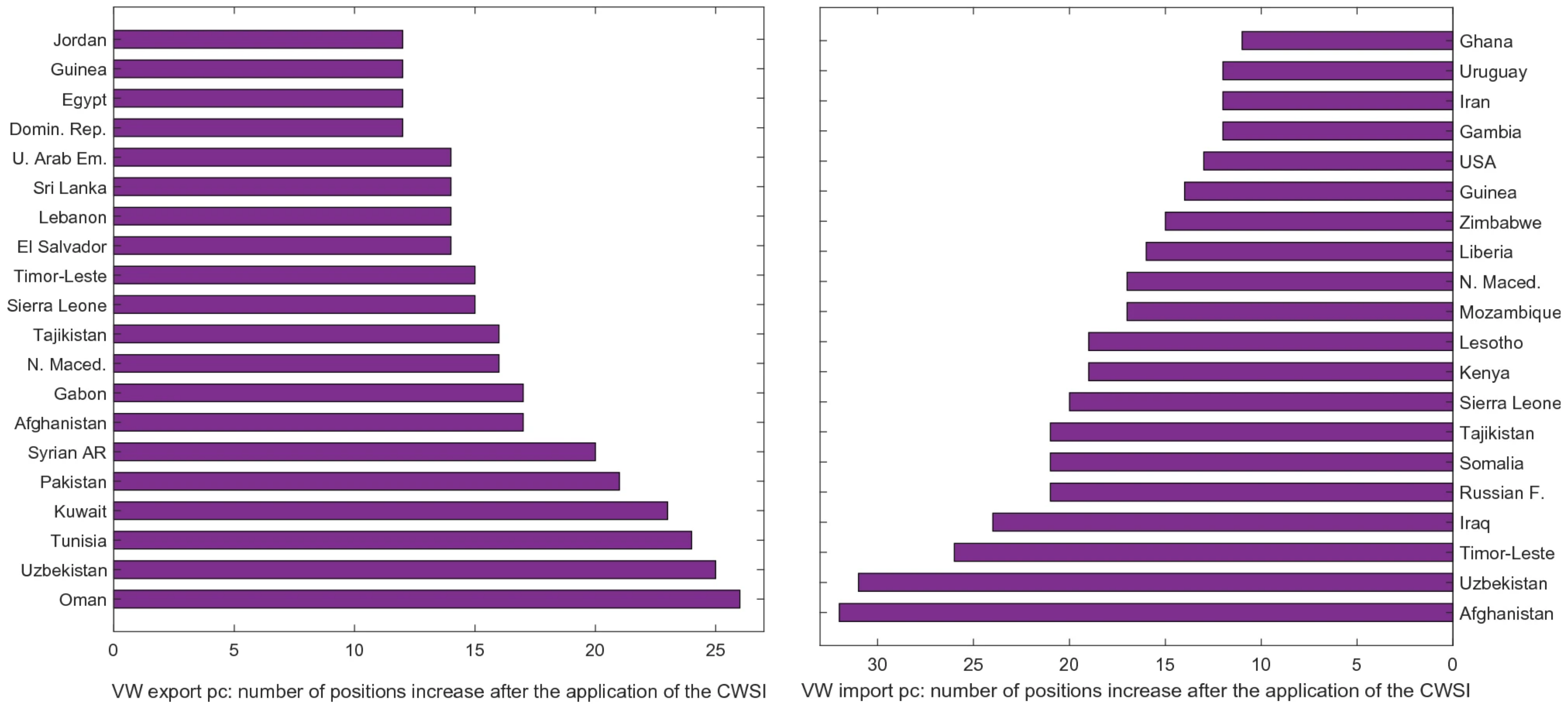
		Volumetric values		Composite scarcity weight				Volumetric values		Composite scarcity weight	
Total (world share)	Net exp	Brazil	9.27	Indonesia	9.71	Per capita (world share)	Net exp	Uruguay	5.31	Paraguay	6.81
		USA	8.24	Brazil	9.46			Paraguay	5.09	Ivory Coast	3.88
		Indonesia	7.39	Argentina	5.71			Australia	3.82	Uruguay	3.87
		Argentina	4.26	Ivory Coast	4.03			Ivory Coast	2.83	Argentina	3.11
		Australia	3.73	Malaysia	2.78			Canada	2.55	Moldova	2.89
		Canada	3.71	Thailand	2.66			Lithuania	2.44	Turkmenistan	2.84
		Russian F.	2.77	Ukraine	2.41			Argentina	2.42	Kazakhstan	2.37
		Ivory Coast	2.73	USA	2.04			Moldova	2.08	Lithuania	2.14
		Thailand	2.15	Paraguay	2.01			Malaysia	1.73	Malaysia	2.08
		Malaysia	2.15	Kazakhstan	1.84			Bulgaria	1.68	Bulgaria	1.89
	Net imp	China	-16.01	China	-15.1		Net imp	Netherlands	-3.81	Netherlands	-5.83
		Japan	-3.38	Netherlands	-4.33			Belgium	-3.12	Belgium	-2.69
		Germany	-3.08	Germany	-3.12			Singapore	-2.71	Singapore	-2.51
		Netherlands	-2.62	Japan	-2.74			Un. Arab Em.	-1.66	Oman	-1.45
		Italy	-2.18	Turkey	-2.26			Israel	-1.34	Benin	-1.11
		Turkey	-2.07	Italy	-2.09			Oman	-1.31	Mauritius	-1.09
		Spain	-1.94	Spain	-2.01			Saudi Arabia	-1.11	Qatar	-1.01
		Egypt	-1.92	Korea, Rep.	-1.68			Kuwait	-1.11	Saudi Arabia	-1.01
		Korea, Rep.	-1.82	Iran	-1.62			Mauritius	-1.05	Spain	-0.99
		Viet Nam	-1.68	Egypt	-1.45			Spain	-1.03	Portugal	-0.96

Largest 20 net CWSI-weighted VW importers per capita (negative values) and largest 20 net CWSI-weighted VW exporters per capita (positive values)



Countries changing status from net importer to net exporter or viceversa





Left panel: 20 countries with the highest increase in position for VW export per capita if the CWSI is applied. Right panel: 20 countries with the highest increase in position for VW import per capita if the CWSI is applied. Rankings are on 149 countries.

Quantifying the information brought by the economic scarcity weight

65% of the net VW exporters per capita in the world have larger net export for the economic-scarcity weighted VW than for the volumetric VW.

All these countries belong to the low- and middle-income group, with Paraguay and Ivory Coast having the largest gap.

17% of the net VW importers per capita in the world have a larger net import for economic-scarcity weighted VW than for volumetric VW.

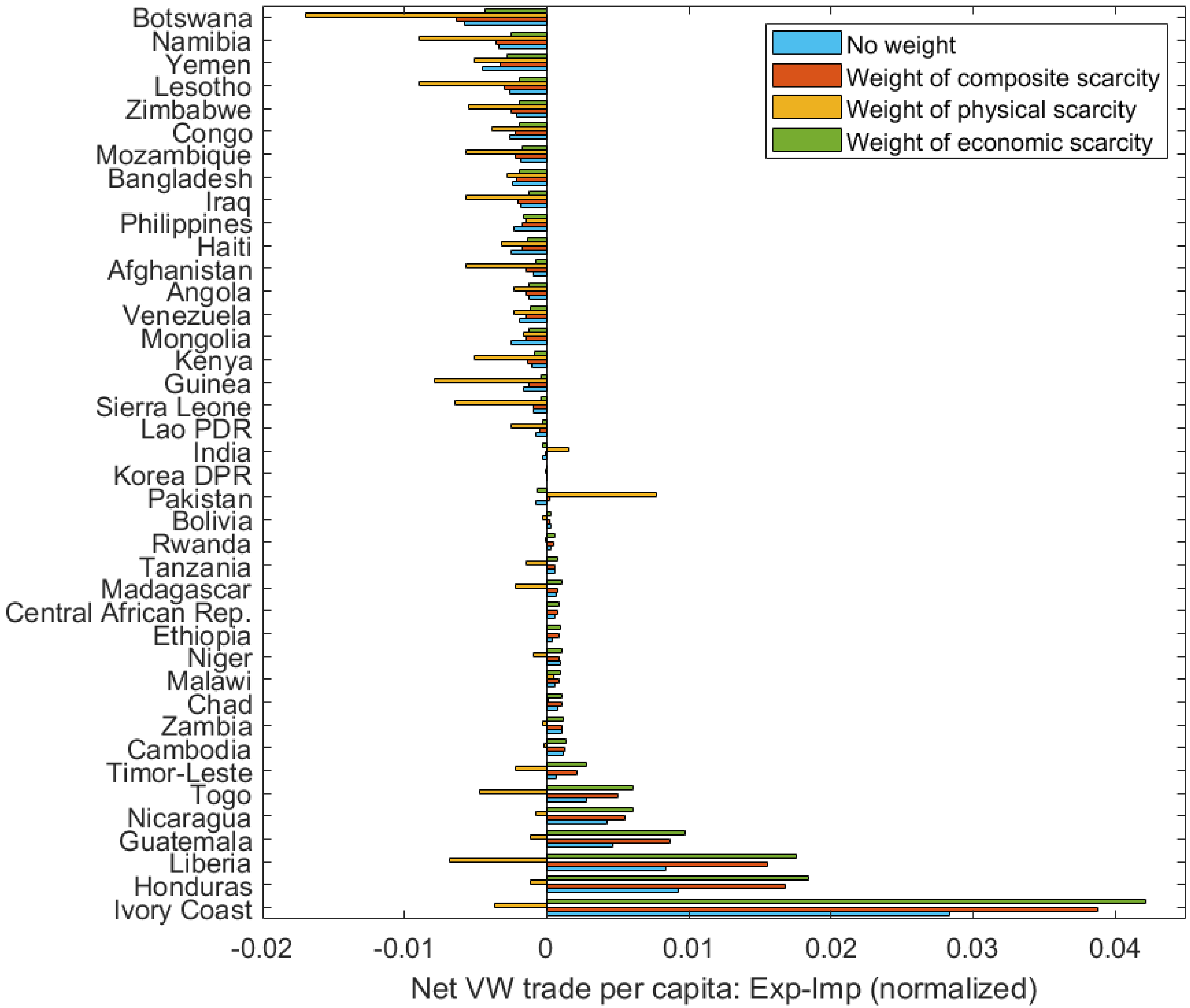
They are both high- and low-income countries, denoting that the consideration of the economic dimension of water scarcity in the trade partners elicits important information on the VW import of both rich and poor nations.

Netherlands and Singapore present the largest gaps.

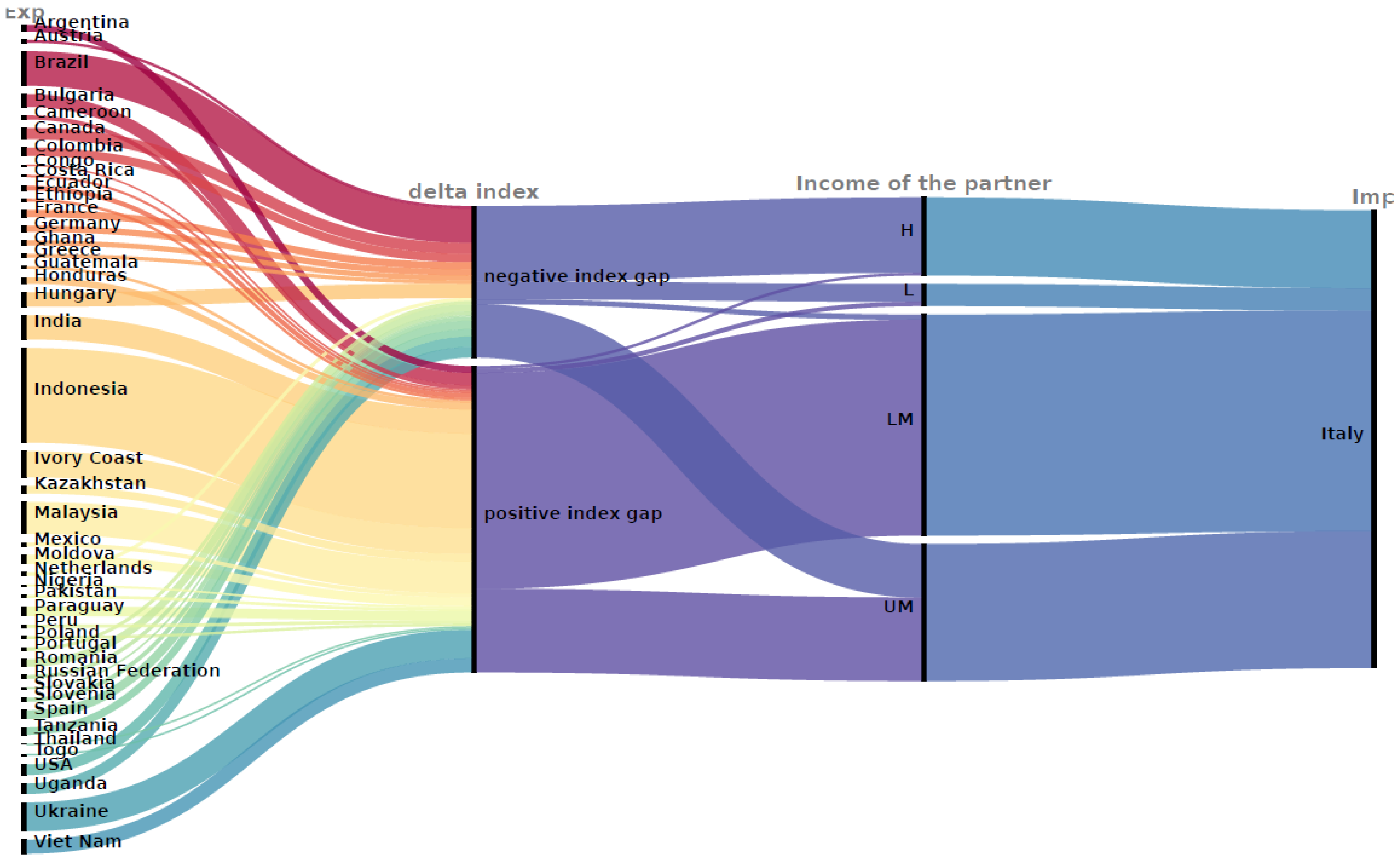
Three high-income countries, among which the USA, shift their status from net exporters to net importers if economic-scarcity weighted VW is considered.

Conversely, seven low-income countries change their situation from being net importers of volumetric VW to being net exporters of economic-scarcity weighted VW.

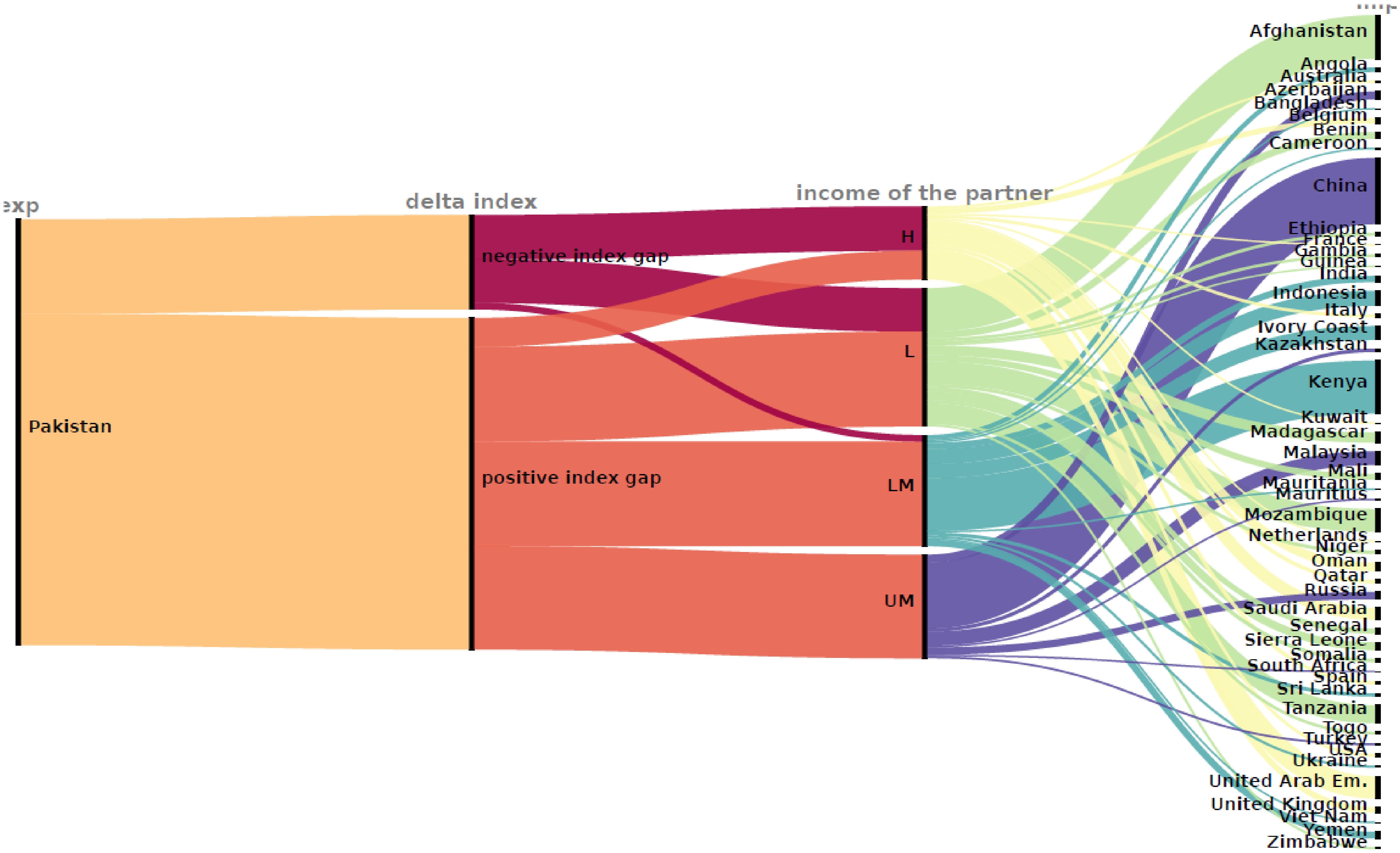
Net VW trade per capita status for 40 countries with the highest prevalence of undernourishment among the overall population, and with a composite water scarcity index higher than 0.5



Italy scarce VW trade
Left: export
Right: import



Pakistan scarce VW trade
Left: export
Right: import



CONCLUSIONS

International bilateral trade fluxes of VW associated to primary crops

Almost half of water volumes flow from countries that are worse-off regarding both composite water scarcity and economic wealth to countries that are better-off for both aspects (e.g. from Mexico to USA).

=>'unfair exchanges'

=> **the economic capability to compensate** for the subtraction of precious water for export purposes may be **lower** for the countries at the origin of these flows. Apparently neither the income derived from the export of primary crops associated to these VW flows, nor the income derived from other sources constitute a compensation for the outflows of scarce water resources

The application of the CWSI generates large changes in positions of countries regarding their share in the global VW use for primary crop export, import and net trade, suggesting that the use of this index allows to elicit a **high amount of information**.

- **High-income** countries have a predominant role in **net import per capita of scarce VW**

  For many of them the application of the **CWSI** reveals the **largest gap** between volumetric and weighted imported VW, and in some cases a **status change from net exporter to net importer.**

- **Low- and middle-income** countries dominate among the largest **scarce VW net exporters per capita.**

  Countries of this category, such as Niger and Congo, also present the **largest gaps** between volumetric and scarcity-weighted VW export, with unbalance toward the latter.

  For many of them economic water scarcity dominates over physical scarcity.

  The application of the CWSI highlights a **change of status** for many of them **from** being **net importers to being net exporters** (e.g. Peru, Pakistan, El Salvador and Dominican Republic).

- **Fragile nations** in terms of food security and water endowment, **export more water and import less water** if the CWSI weight is applied to VW trade fluxes.

Despite the largest players for scarce VW import (in total and per capita) are dominated by high income countries, the application of the CWSI at a global scale reveals a **more complex scenario**, in which the group of the **20 countries having the largest difference between unweighted and weighted VW import is composed by mixed countries** with respect to economic wealth and water dimension.

Mutual exploitation of physically and economically scarce water **among poor countries**.

The inclusion of the dimension of economic water scarcity into the composite scarcity index (CWSI) has been crucial to map in a more precise way the global VW trade dynamics.

High income countries consume large volumes of water that for lower income countries is scarce from both physical and economic perspectives. => food processing or rexport (Kastner et al. 2015) => The considerable economic value added created by these activities (Dorninger et al. 2021) is channeled, among other uses, for purchasing further quantities of primary crops from the same countries => **structural patterns of unequal use of scarce water at a global level**.

Compensation policies?

Thank you

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