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Massimo Riccaboni
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**Tiziano Distefano**
IMT Institute for Advanced Studies Lucca

**Massimo Riccaboni**
IMT Institute for Advanced Studies Lucca

**Giovanni Marin**
Ceris-CNR, Institute for Economic Research on Firms and Growth, National Research Council

# Global Virtual Water Trade: Integrating Structural Decomposition Analysis with Network Theory

Tiziano Distefano* Massimo Riccaboni† Giovanni Marin‡

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**Abstract**

The consideration of both the direct and the indirect effects of global production and trade is the first step in order to assess the sustainability of resource exploitation, in particular water usage. This paper applies the Global Multi-Regional Input-Output model to quantify the interdependencies of different sectors and to determine the overall water consumption of each country. This procedure allows the measurement of Virtual Water Trade, that is the volume of water embedded in traded goods. This paper introduces further extensions based on network analysis to overcome the limitations of I-O models. To the best of our knowledge, this is the first attempt to build a bridge between two different, but related, methodologies.

Firstly, we assess the evolution of the structure of international trade in Virtual Water (VW). Secondly, we present the results from the Structural Decomposition Analysis. Finally, we introduce other measures from Network Theory, in order to integrate the previous results. Community Detection assessment reveals the emergence of regional VW systems composed by a limited set of countries. Thus our study confirms the need of elaborating and implementing transboundary policies for water management, especially in the European Union.

**Keywords:** virtual water trade, multi-regional input-output model, network analysis, community detection
**JEL:** C67, Q25, F18

*Corresponding author. IMT Institute for Advanced Studies Lucca, Piazza S. Ponziano 6, 55100 Lucca (Italy). E-mail: tiziano.distefano@imtlucca.it.

†IMT Institute for Advanced Studies Lucca, Piazza S. Ponziano 6, 55100 Lucca (Italy). E-mail: massimo.riccaboni@imtlucca.it

‡Ceris-CNR, Institute for Economic Research on Firms and Growth, National Research Council of Italy, Via Bassini 15, 20121 Milano (Italy); SEEDS Sustainability Environmental Economics and Dynamics Studies, Ferrara (Italy). E-mail: g.marin@ceris.cnr.it

# 1 Introduction

Global trade virtually transfers large amounts of water resources from areas of production to far consumption regions, a phenomenon that has been named "the globalization of water" [14] especially important for food security[17], conflicts for water [4] and overpopulation [26]. Carr et al. [7] show some interesting features of the Virtual Water Trade (henceforth VWT): by 2010 the majority of the global population is becoming net importer of virtual water.

Hitherto the two main methodologies applied in the computation of VW are: Input-Output Analyses (I-O) and Network Theory, which are two different but analogous approaches. Among the vast literature of I-O study of VW ([3], [19], [27],[29]) we quote Antonelli et al. [2] who notice that VW is an "inherently economic concept", which is consistent with standard international trade theory [25]. Water is cheap where it is abundant, but the opposite is not necessarily true: water resources may not be correctly priced and property rights may not be adequately enforced, so that the cost of water could be kept inefficiently low. The capacity to engage in trade enables water-scarce countries to obtain water and achieve food security. Virtual water trade (VWT) is thus a securitizing rather than a saving process. I-O tables express the value of economic transactions occurring between different sectors of an economy, so that it is possible to account for sectoral interdependencies in the economic system. This technique considers the indirect consumption of water, due to the use of intermediate production factors.

On the other hand Network Theory has been extensively used to analyse World Trade ([31]), including application to VWT ([17], [12], [7]), because it enables to find non linear relationship among the nodes involved in the international trade. To the best of our knowledge, this is the first paper which combines these approaches, applying Network Theory to I-O data to investigate the patterns of VW at the global level.

The remaining of the paper is organised as follows. Section 2 and 3 describe the dataset and introduces the global distribution of direct water usage. Section 4 introduces and explains the Input-Output Methodology, in order to frame the results regarding the virtual water debt. Section 5 discusses the results of the Structural Decomposition Analysis (SDA). Section 6 introduces the Network methodology and the fundamental topological properties of the global virtual water trade. In particular the Community Detection allows us to establish a bridge and integrate the information given through the SDA. Finally Section 7 draws the conclusions.

# 2 Data

WIOD[1] gives the opportunity to assess the environmental impact of economic activities, such as water consumption, land use and air emissions, by exploiting information on world interindustry flows of intermediates. The database contains data about 40 countries (EU, USA and other important developing country, i.e. India, China and Brazil among others) and 35 sectors for each country. For every year we have the square matrix of 1435x1435 bilateral flows of intermediate inputs (input-output)[2]. WIOD is composed by a set of harmonized supply, use and symmetric I-O tables, valued at current and previous year's prices.

Accounts are measured in basic prices, that means that all values in the intermediate and final use blocks represent the amount receivable by the producer from the purchaser. In particular this valuation ensures that any trade and transport margins to be paid by purchasers are recorded in the trade and transport rows. Summing over all intermediate inputs in a column of the WIOT (World Input Output Table), one obtains the total intermediate inputs used by an industry at purchasers' prices. Summed to value added at basic prices (which includes wages, profits and (net) taxes on production), one obtains output at basic prices.

Agricultural water use in WIOD has been estimated using crop and livestock water intensities from Mekonnen and Hoekstra (2011) [15] and data on crop production and livestock from FAOSTAT. The use of water by the electricity sector for hydro-power generation has been calculated using the world average water use per unit of electricity estimated by Mekonnen and Hoekstra (2011) [15] and the hydro-power generation from the IEA. The use of water in other economic sectors has been calculated using the total water use in industry reported by Mekonnen and Hoekstra (2011) [15], the shares of water use by industry of EXIOPOL and the gross output at constant prices from WIOD. Population data are available from the World Bank web site (http://data.worldbank.org/).

[1]World Input Output Database, http://www.wiod.org, updated in May 2013. The most recent version, released in November 2013, does not include price-deflated tables and environmental accounts.

[2]There are 40 countries plus the ROW, then $41 \cdot 35 = 1435$.

Table 1: Top users of Blue, Green and Grey water both at national level and per capita.

| NATIONAL km3 = Wuse_SECTOR + HH on 1995 | | | | | |
|---|---|---|---|---|---|
| BLUE | | GREEN | | GREY | |
| IND (15.86%) | 246.551 | IND (12.15%) | 726.534 | CHN (23,9%) | 288.893 |
| CHN (11.76%) | 182.833 | USA (10.90%) | 651.698 | USA (15,23%) | 184.025 |
| USA (11.66%) | 181.333 | CHN (10.65%) | 636.769 | IND (13,54%) | 163.603 |
| CAN (5.66%) | 86.439 | BRA (6.27%) | 374.887 | RUS (4,75%) | 57.437 |
| BRA (4.86%) | 75.669 | RUS (5.03%) | 300.921 | BRA (2,38%) | 28.822 |
| RUS (3.66%) | 57.412 | IDN (4.30%) | 257.570 | CAN (2,23%) | 26.992 |
| JPN (1.63%) | 25.350 | CAN (2.05%) | 122.647 | IDN (2,03%) | 24.493 |
| 1000m3 PER CAPITA 1995 | | | | | |
| BLUE | | GREEN | | GREY | |
| CAN | 2.945 | AUS | 5.298 | CAN | 0.920 |
| SWE | 1.923 | CAN | 4.178 | BGR | 0.716 |
| AUT | 1.181 | USA | 2.447 | USA | 0.691 |
| AUS | 0.897 | BRA | 2.316 | HUN | 0.561 |
| USA | 0.681 | BGR | 2.178 | SVN | 0.469 |
| FIN | 0.657 | RUS | 2.031 | AUS | 0.394 |
| GRC | 0.475 | HUN | 1.990 | RUS | 0.388 |
| Population (milion) 1995 | | | | | |
| CHN (21.14%) | 1204.855 | IND (16.77%) | 955.804 | USA (4.67%) | 266.278 |
| IDN (3.40%) | 194.113 | BRA (2.85%) | 161.891 | RUS (2.59%) | 148.141 |
| JPN (2.24%) | 125.439 | ... | ... | GBR (1,01%) | 58.020 |
| CAN (0.51%) | 29.340 | AUS(0.31%) | 18.070 | ROW (33,25%) | 1894.550 |

# 3 Global distribution of water usage

We first discuss the most common definitions of Water Footprint present in the current literature. The water footprint, originally proposed by Hoekstra and Hung [16], in analogy to the ecological footprint [24], originates from the concept of virtual water proposed by Allan [1]. We assess the global water consumption based on the concepts of blue, green and grey water of the Water Footprint approach [15]. Conventional national water use accounts are restricted to statistics on water withdrawals within the territory of a country. The approach proposed by Hoekstra et al. gives a broader perspective of humans' appropriation of freshwater. In what follows these concepts are described in detail.

*Blue Water Footprint* (henceforth **B**): it is an indicator of consumptive use of fresh surface water or groundwater. The term "consumptive water use" refers to one of the following four cases: (i) water evaporates; (ii) water is incorporated into the product; (iii) water does not return to the same catchment area, for example, it is returned to another catchment area or the sea; (iv) water does not return in the same period, for example, it is withdrawn in a scarce period and returned in a wet period. The concept of blue water is particularly important due to its alternative uses. The relevance of virtual blue water trade is linked to the possibility of diverting water away from agriculture, where its marginal value is generally low.

*Green Water Footprint* (henceforth **GN**): it is an indicator which refers to the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. The green water footprint is the volume of rainwater consumed during the production process.

*Grey Water Footprint* (henceforth **GY**): it is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards. The grey water footprint concept has grown out of the recognition that the size of water pollution can be expressed in terms of the volume of water that is required to dilute pollutants such that they become harmless.

Table 1 compares the total amount of water used both at country level and per capita. Given the stability of the distribution and of the ranking during the considered time span, we present the amounts of B, GN and GY water consumed in 1995 and 2009. These volumes stem from the estimation of water used by households, on the basis of the average domestic water supply, and industry, reported in Mekonnen and Hoekstra [15].

There are three facts that emerge from the results reported by the Table 1.

1. There is an uneven distribution of direct water use both at country level and per capita. The first 3 countries (China, India and USA) are consuming alone in 2009 (1995) 41.37% (39.28%) of B, 31.02%

(33.70%) of GN and 57.81% (52.67%) of GY.

2. The distribution and the rank does not change substantially, with some developing countries playing a key role.

3. The population size seems to be a key factor, since that China and India account, together, for 2.5 billion of people, that is almost 35% of the world population. However, the percentage of consumption at national level seems to increase more than the population growth, therefore we may care about indirect consumption, trade balance and technological shifts in order to explain which are the forces that shape the global distribution of water.

The main questions we try to answer are: who is really consuming the water? which is the distribution of responsibility for water depletion? It is worth to distinguish between B and GN, given that they differ in many aspects, and their ratio varies substantially over time and space. Green water supply comes from rainfall and is scarce in arid and semiarid areas. As such it is highly immobile and in general it is not explicitly valued by users. Conversely, blue water is mobile, it can be abstracted, pumped, stored, treated, distributed, collected, and recycled. Normally, its supply is costly, because it requires infrastructure. It is possible to indicate, among others, two important variables that explain water use: population size and infrastructures. Although its definition is less clear, we should not ignore grey water which gives a clue about the pollution of water. The list is basically unchanged but the contribution of each country varies substantially: China alone covers more than the 30% of the global amount. The process of globalization has seen China to become the core of global production, in part confirming the pollution heaven hypothesis [6]: a reduction in trade barriers will lead to a shift of pollution-intensive industries from countries with stringent regulations to countries with weaker regulations, typically developing countries such as China and India.

Figure 1 shows the size[3]-rank distribution, by aggregating some years of interest: 1995, 2001 and 2009. From these graphs we have a first insight about the uneven but stable distribution of water consumption per capita, whose shape seems to swing from an exponential distribution, for B and GY, to a power law (in the upper tail) for GN.

To assess the type of distribution followed by green water, we estimates the following OLS regression in the upper tale of the distribution (about half of the sample):

$$ln(Size) = a + b \cdot ln(Rank) + \epsilon \tag{1}$$

where the error term $\epsilon$ is assumed to be iid. Here b = -0.5253, then we would infer that, at least in the upper tail, S $\sim$ R$^{-0.5253}$, so the gap between GN use should be smaller than a Zipf law (that is b = -1).

The second regression, estimated for B and GY, tests the exponential distribution:

$$Size = a \cdot exp(Rank \cdot b) \tag{2}$$

that fits pretty well the whole distribution with significant coefficients: $a_B$=-1.146, $b_B$=-1.059 and $a_{GY}$=0.531 $b_{GY}$=-1.352. The similarity in terms of level of consumption per capita and shape of the distribution for B and GY could be due to the fact that both are strictly dependent from the industrial structure which is needed both to "extract" (blue) water and to dilute pollutants (grey water).

# 4 Global Multi-Regional Multi-sectoral Input Output Model

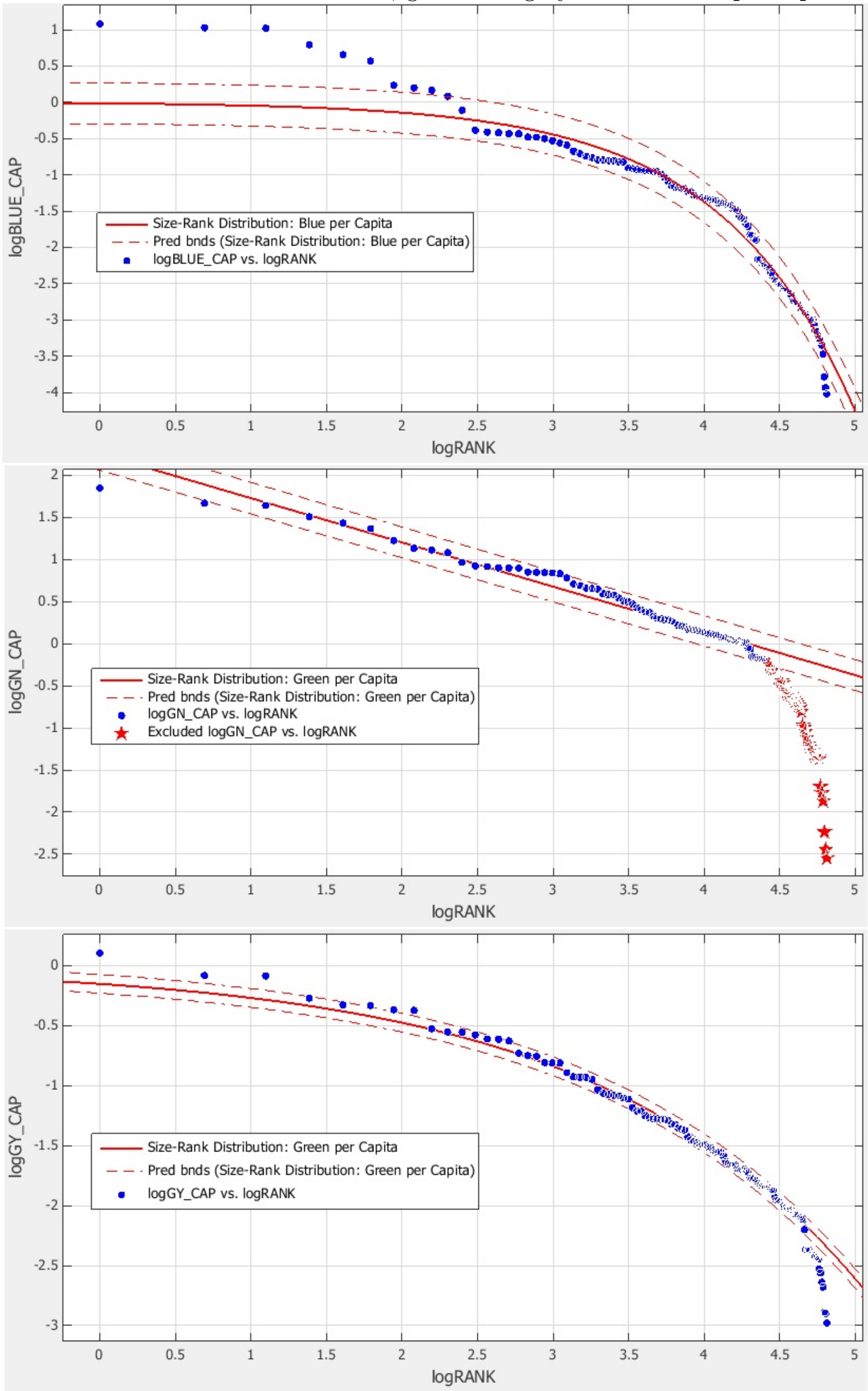
Global trade involves all countries, each of which has a technology of production given by the different composition of sectors. A natural approach to deal with this framework is the application of Global Multi-Regional Multi-sectoral I-O Model [18] (GMR-MS-IO) where there are N regions (countries in our case) r composed by the same number of sectors s, then the world matrix of intermediate exchanges is composed by (N·s x N·s) elements. In particular this approach allows to exploit both information about the exchange within a country from sector i to sector j ($z_{ij}^{NN}$) and international trade from country E to country I ($z_{ij}^{EI}$), with possibly i and j equals[4]. The input-output model proposed by Leontief is characterized by the following assumptions [29]:

- linear technology of production with fixed coefficients, then it does not allow substitutability among intermediate inputs;

[3] Here size represents the level of water consumption per Capita.

[4] In our case, given the high level of aggregation, each sector is actually composed by several firms and sub-sectors, then we find positive values even on the diagonal. This means that there are positive exchange within a sector of a given country.

Figure 1: Rank-Size distribution of blue, green and grey water consumption per Capita.



- production in a Leontief system assumes constant returns to scale (CRS) in intermediate inputs;
- it is assumed that the overall effect of many simultaneous activities is simply the sum of the effect of each singleton, then there is no room for synergies in the production process;
- in the static framework there is no technological progress. However through the decomposition analysis it is possible to disentangle the role played by technical change when two or more years are considered;
- it is assumed that the economy is demand-driven, then the supply should always be able to satisfy any increase without affecting the prices;
- Input-Output tables are generally constructed in monetary units for national accounting purposes, although, especially in the environmental context, it would be better to consider physical units.

In what follows we describe the logic of MR-MS-IO, the notation and the main equations that will be used in Section 3. As described in Miller and Blair [18], let assume, without loss of generality, that there are two countries (E,I) composed by three sectors each (a,b,c). The aggregate I-O table Z of intermediate exchanges has, on the diagonal, the square matrices $Z^{EE}$ and $Z^{II}$, that represent domestic interindustry flows, while off-diagonal matrices $Z^{EI}$ and $Z^{IE}$ represent interindustry flows across countries (i.e. international trade in intermediates). In particular, each element $z_{ij}$ indicates the amount of intermediate exchange from sector i to sector j, i.e. the entry $z_{ij}^{EI}$ is the volume of trade from sector i of country E to sector j of country I.

$$\left(\begin{array}{ccc|ccc} z_{aa}^{EE} & z_{ab}^{EE} & z_{ac}^{EE} & z_{aa}^{EI} & z_{ab}^{EI} & z_{ac}^{EI} \\ z_{ba}^{EE} & z_{bb}^{EE} & z_{bc}^{EE} & z_{ba}^{EI} & z_{bb}^{EI} & z_{bc}^{EI} \\ z_{ca}^{EE} & z_{cb}^{EE} & z_{cc}^{EE} & z_{ca}^{EI} & z_{cb}^{EI} & z_{cc}^{EI} \\ \hline z_{aa}^{IE} & z_{ab}^{IE} & z_{ac}^{IE} & z_{aa}^{II} & z_{ab}^{II} & z_{ac}^{II} \\ z_{ba}^{IE} & z_{bb}^{IE} & z_{bc}^{IE} & z_{ba}^{II} & z_{bb}^{II} & z_{bc}^{II} \\ z_{ca}^{IE} & z_{cb}^{IE} & z_{cc}^{IE} & z_{ca}^{II} & z_{cb}^{II} & z_{cc}^{II} \end{array}\right) \tag{3}$$

Let x be the vector of total output, given by the (row) sum of intermediate exchanges plus the final demand:

$$x = Z \cdot i + f \tag{4}$$

where i is a vector of ones. Note that by construction the total output of each sector must be equal to its outlay.

It is possible to split the system among the different regions, hence also x is composed by $x^E$ and $x^I$ given the presence of two countries. Here f is the vector of final demand which, for simplicity is split into domestic demand and export[5]. Starting from the above matrices we compute the matrix of technical coefficients, which describes how the product of each row is distributed among the other sectors:

$$A = Z \cdot \hat{x}^{-1} \tag{5}$$

where $\hat{x}$ is a diagonal matrix composed by the inverse of the elements in x, let say $\frac{1}{x_i}$ $\forall$ i $\epsilon$ x. Since A has the same structure of Z, we may recover the domestic matrix block $A^{EE}$, $A^{II}$ and those with the international intermediate trade: $A^{EI}$ and $A^{IE}$. Finally it is possible to build the Leontief inverse matrix which solves the linear system: x = A·x + f. Each element $l_{i,j}$ of the matrix L indicates how much the production of sector j must increase given an unitary increase in the demand of good i. Matrix L captures not only the direct links (A) but also the indirect ones.

$$L = (I - A)^{-1} \tag{6}$$

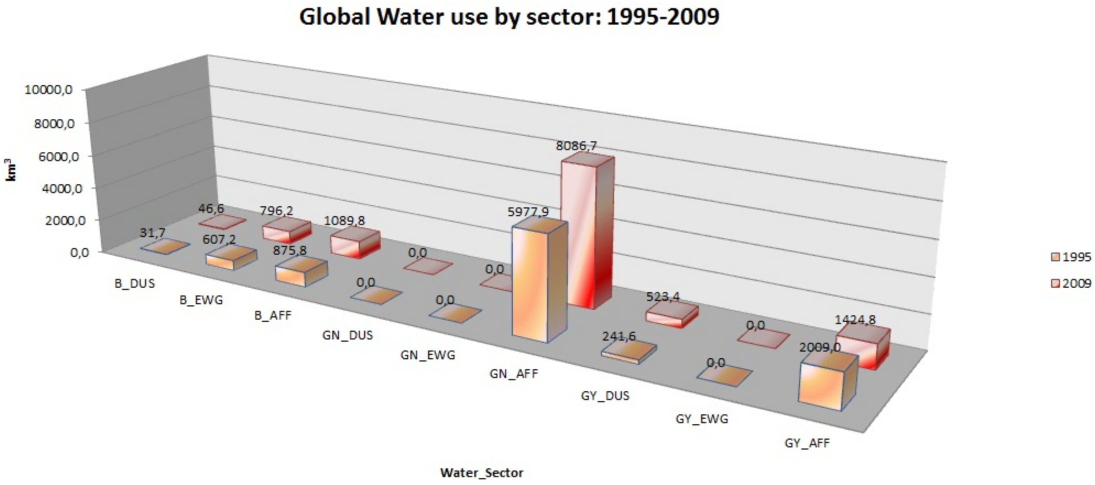
In order to compute the indirect use of water at the global level, we define the water intensity with the respect to total output. Let w be the vector of total water consumption of each sector, then:

$$v = w \oslash x \tag{7}$$

where v is the vector which expresses the amount of water ($m^3$) in terms of (1000 dollar worth of) total output. Here $\oslash$ is the Hadamard product, which, in this case, is the element-wise ratio for two vectors of same

[5] In this case the sum of all final demands is equal to traditional definitions of Gross Domestic Product, i.e, net of imports. Under these circumstances it is possible to have negative values in the export matrix.

Figure 2: Global Water use at sectoral level in 1995.




dimensions[6]. From vector v we may unravel the indirect use of water due to to intermediate exchanges through the matrix $\Theta$:

$$\Theta = \hat{v} \cdot L \tag{8}$$

Each element $\theta_{ji}$ of the matrix $\Theta$ represents the overall water impact of an increase of final demand for each sector in each region. Then the row sum returns the global increase that sector j must satisfy to supply all the other (intermediate) sectors.

## 4.1 International VWT

Figure 2 shows the global distribution of water consumption by sector.

The figure highlights two important facts. First, as expected, only the Agriculture, Hunting, Forestry and Fishing (AFF) sectors and the Electric, Gas and Water supply (EGW) sectors show a great direct usage of blue water, where the first represents in 2009 (1995) 56.15% (57.82%) of total and the latter 41.02% (40,02%) of total. The most important countries for the EGW production (billion of dollar (B$)) are, in 2009 (1995), Japan 261.6 (252.3), USA 387.5 (238.5), France 111.7 (136.9) and China, that in 2009 became the leader with 481.8 B$. For AFF, we find for 1995 the USA (237.3), China (236.2) and Japan (169.2), while in 2009 China 880.42. USA 342.5 and India 271.7, with a clear increasing role of emerging countries. In case of GY, the AFF and the Fd (Food, Beverages and Tobacco) are the biggest sectors with 65.29% (68.94%), but we can see that also the following sectors have a relevant impact: Tx (Textiles and Textile Products), OMet (Other Non-Metallic Mineral), Met (Basic Metals and Fabricated Metal), Pp (Pulp, Paper, Printing and Publishing) and CH (Chemicals). All these sectors, but Fd, are aggregated with the label “DUS” covering the 34.71% (31.05%). In terms of production we find that the following countries are the most important: USA 1175 B$, Japan 1122 B$ and Germany 485 B$ in 1995, while in 2009 we find: China 2902 B$, USA 1600 B$ and Japan 981 B$.

As regards green water, only the AFF presents positive amounts of consumption for a total amount of 5977 $km^3$, much higher than the total blue water (1515 $km^3$) and grey water (944 $km^3$) put together in 1995. The increase is dramatic if we consider 2009: GN rose to 8086.7 $km^3$, B to 1941 $km^3$ and GY to 1508 $km^3$. The annual average growth rates[7] were 1.67%, 2.03% and 3.19%, respectively.

We exploit the I-O model to disentangle the main forces which drive water use and distribution and their evolution over time. In what follows we show how the international trade of intermediate and final goods, with its load of embedded water, allows some country to use a greater amount of water than its own domestic resources. This is the base of the “water debt” concept: as expected the developed countries are, in general, debtor with the respect of the developing countries. We apply a SDA to specify the impact and the growth of

[6] In this case v, w and x are column vectors with 1435 entries given by the data for 40 countries and Row which are decomposed into 35 sectors.

[7] In order to compute it let assume a compound interest regime, so that after t years an initial capital C yields an amount M = $C \cdot (1+i)^t$, then the yearly average growth rate is i = $\sqrt[t]{\frac{M}{C}}$ - 1.

each of the main factors: water intensity efficiency (v), technological shift (through the Leontief inverse) and size and composition of final demand. The analysis compares different years by considering only the volume exchanged: in case of the Virtual water trade we consider all the monetary values at the same base year (1995), while in the SDA we apply the additive chaining technique [9], with the values at previous year's price, which allow the computation of the growth only in physical term.

First, we define the virtual water embodied in the exports ($\Theta_{Exp}$) and imports ($\Theta_{Imp}$) of both intermediate and final goods, from which we may calculate the water trade balance: $\Theta_{BAL} = \Theta_{Exp}$ - $\Theta_{Imp}$. The virtual water embedded in export and import are given by, e.g. for country C:

$$\Theta_{Exp,C} = \sum_{k=1}^{N} \Theta_{Ck} \cdot (f_k - f_{kC}) \tag{9}$$

while:

$$\Theta_{Imp,C} = \sum_{k=1}^{N} (\tilde{\Theta}_k - \Theta_{Ck}) \cdot f_{kC} \tag{10}$$

where:

$$\tilde{\Theta}_k = \sum_{j=1}^{N} \Theta_{jk} \tag{11}$$

and N is the number of countries (40 + ROW). Here $f_{CC}$ is the domestic demand, while $f_{kC}$ represents the vector of export from country k to C, and $f_k$ is the row sum for each sector in country k. Let $\Theta_{ij}$ be a square sub-matrix which shows the Leontief inverse for country i, when it exports to j, multiplied by their water usage, as in equation (9). Notice that $\Theta_{CC} \cdot \sum_{k \neq C}^{N} f_k$ returns the water need in country C when producing goods and services for final use which are exported to all the other countries. Whilst, given $k \neq C$, it is possible to recover the water need in country C when producing the intermediate exports that are used abroad to produce final goods and services consumed by country k: $\Theta_{Ck} \cdot \sum_{k \neq C}^{N} (f_k - f_{kC})$.

Figure 3 shows that international trade has an high impact on the capability of a country to face its domestic requirements. In particular we can observe a progressive diversion of virtual water from the developing (Asian) to the developed countries. The figure shows the water trade balances of the main macro-areas in which we split the countries given in WIOD[8]: EU, $EU_{EST}$, USA, south America ($AM_S$), the Less developed countries in Asia ($ASIA_{LDC}$) and more developed ($ASIA_{DC}$), and the ROW plus Canada and Australia. The tables with the details for each country and sector are reported in the Appendix (tables 5 and 6, respectively).

In all three cases we find a tendency of the globalization to move the production from the richer countries to less developed countries making them the core of production, and export. Amongst the main net importer we find: USA, Japan, Germany and Great Britain. Surprisingly even Russia is becoming, in 2009, one of the greatest net importer of green water with 55 $km^3$. The main finding substantial increase in the amount of grey virtual water exchanged from 2001 to 2005. This is due mostly to the fast economic growth and industrialization of China which has seen an increase in its export of GY from 32 to 132 $km^3$, that is the 44% of the whole amount of GY exported at global level. We confirm the increasing relevance of the AFF and DUS sectors. On the other hand, the main exporter of GN, if we exclude the ROW, is Brazil with almost 135 $km^3$. Also India and Canada are big exporter of both GN and BW, even though a sectoral analysis allows to disentangle the sources of this apparent analogy. In fact India is mainly exporting products of the AFF sectors (almost 16 $Km^3$) while Canada is a net importer of AFF (-5 $Km^3$) but a big exporter in terms of EWG products (almost 18 $Km^3$). Results for Russia are of particular interest. Russia shows in 2009 a $\Theta_{BAL}$ of only 1 $Km^3$ for both B and GY. This apparently could mean that it is neutral in terms of global footprint. Russia shows big volumes of trade and virtual import of BW from the EWG and of GY from the DUS. At the other hand it is a big exporter of AFF products which compensate the virtual water imported.

[8] Here the list of countries included in each macro-area:

- EU: AUT, BEL, DEU, DNK, ESP, FRA, GBR, IRL, ITA, NLD, PRT
- EU-EST: BGR, CYP, CZE, EST, FIN, GRC, HUN, LTU, LUX, LVA, MLT, POL, ROU, RUS, SVK, SVN, SWE, TUR
- ASIA-LDC: CHN, IDN, IND, TWN
- ASIA-DC: JAP, KOR
- AM-S: BRA, MEX

Figure 3: Global Water Trade Balance: 1995, 2001 and 2009.

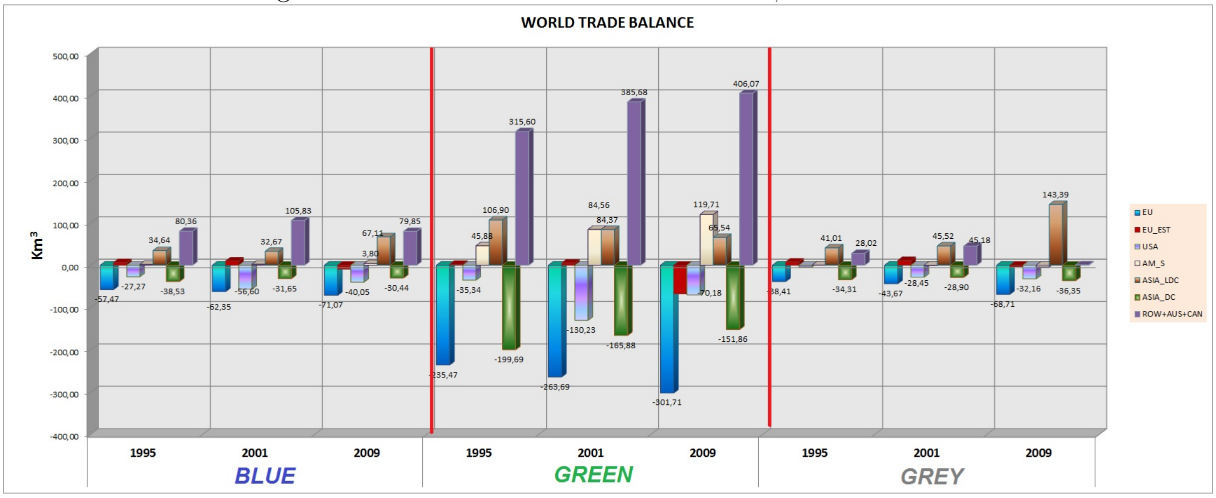



Figure 4: Global Water Export dynamic: 1995 to 2009.

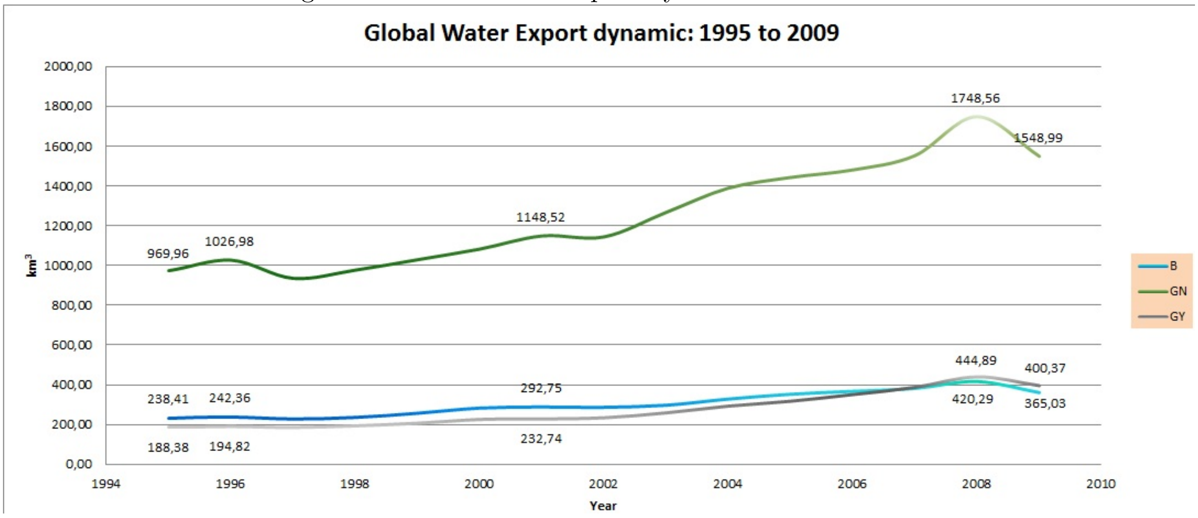



Figure 4 shows the increasing relevance of international trade, and then export, on footprint for all the three categories of water under assessment. In particular, B has grown from 238.41 to 365.03 km$^3$, GN from 969.96 to 1548.99 km$^3$ and GY from 188.38 to 400.37 km$^3$. Moreover, the impact of the international crisis is evident, since all aggregates have reached their peak in 2008, showing a decrease of more than 10% in 2009.

The figure shows the non-linear dynamics of the level of export of virtual water. The sources of heterogeneity are multiple: the evolution of population structure and life stiles, the impressive process of industrialization experienced mostly in Asia and Latin America and the process of delocalization, among others.

We assess the evolution of industrial structure and final demand and their impact on virtual water distribution through SDA. This analysis will be merged by Network tools in order to unravel the topology and the connections between the industrial sectors.

# 5 Structural Decomposition Analysis

By following Wilting et al. [30] and Su and Ang [5] we present the additive decomposition of the following equation which describes the increase from year t-1 to year t of the total water use:

$$\Delta w = w_t - w_{t-1} = \Theta_{IE} + \Theta_{TECH} + \Theta_{SIZE} \tag{12}$$

where:

Table 2: Structural Decomposition Analysis from 1995 to 2009: additive aggregation.

| WATER | $\Theta_{IE}$ | $\Theta_{TECH}$ | $\Theta_{SIZE}$ | $\Delta$ W |
|---|---|---|---|---|
| B | - 39.92% | 10.17% | 57.90% | 28.15% |
| GN | - 13.67% | - 2.30% | 51.25% | 35.27% |
| GY | - 6.67% | - 0.71% | 67.05% | 59.67% |

$$w_t = \hat{v}_t \cdot L_t \cdot f_t \tag{13}$$

It has long been recognized in the literature on SDA that there is not a unique way to do a decomposition. The results may differ significantly across the alternative procedures (see [10]; [5] for comparisons). To overcome the non-uniqueness problem, Dietzenbacher and Los [10] have proposed to use the average of all possible decomposition forms. In the case of n determinants (or variables), the number of alternative decompositions is n!. They also showed that the average of all decompositions can be adequately approximated by the average of the two so-called polar decomposition forms. The first polar form is derived by starting the decomposition with changing the first variable first, followed by changing the second variable, changing the third variable, and so forth. The second polar form is derived exactly the other way around, i.e. changing the last variable first, followed by changing the second-last variable, and so on.

$\Theta_{IE}$ represents the intensity effect, that is the variation of water use for any unit of output (v).

$$\Theta_{IE} = \frac{1}{2}[\Delta v \cdot L_t \cdot f_t + \Delta v \cdot L_{t-1} \cdot f_{t-1}] \tag{14}$$

$\Theta_{TECH}$ represents the variation of Leontief coefficients and then of the technological structure. Since we are dealing with static comparative analysis, it returns the variation in water requirement whether, by keeping all the other variables unchanged, the structure of matrix L has changed.

$$\Theta_{TECH} = \frac{1}{2}[\hat{v}_{t-1} \cdot \Delta L \cdot f_t + \hat{v}_t \cdot \Delta L \cdot f_{t-1}] \tag{15}$$

Finally $\Theta_{SIZE}$ represents the variation of virtual water due to changes in the volume of final demand, both at domestic and international level:

$$\Theta_{SIZE} = \frac{1}{2}[\hat{v}_{t-1} \cdot L_{t-1} \cdot \Delta f + \hat{v}_t \cdot L_t \cdot \Delta f] \tag{16}$$

By using the additive chaining technique [5] we may recover the whole variation, from the first and the last year of interest, simply by summing consecutive one-year decompositions:

$$\Delta w_{(T,0)} = w_T - w_0 = \sum_{\tau=1}^{T} \Delta w_{(\tau,\tau-1)} \tag{17}$$

Table 7 in the appendix shows the variation due to IE, TECH and SIZE for each country and for each category (B, GN and GY), whilst Table 2 shows the weighted average of contribution of each component with the respect of the initial volume (based on 1995) of water consumed by each country. Surprisingly, it seems that each increase in efficiency (here $\Theta_{IE}$) which would save resources is more than compensated by the increase in consumption (here $\Theta_{SIZE}$). Hence the net effect is positive, in the sense that virtual water use is demand driven. As expected $\Theta_{TECH}$ does not show great variation because the changes in the technological structure take long time.

As expected, in almost all countries, and in each water category, there is a positive impact due to the increasing demand, with the highest variation occurring in China, India, Brazil, Russia and USA.

**B:** almost all countries show a negative impact of $\Theta_{IE}$, in particular China (-60.96%) and Australia (-46.41%), whereas in Brazil there is an increase by 3.06%. It is worth noticing a great divergence between the impact of a variation in L in two important developing countries such as: China (+22.89%) and India (-18.98%).

**GN:** here we observe great heterogeneity across countries in which there is a positive impact of $\Theta_{IE}$ with a range of variation that goes from +10% to +43% (Spain); conversely, a negative sign is found for China(-35%). From $\Theta_{TECH}$ we find similar results, with the range of positive effects ranging between 3% and 13% (France) while negative values are mostly present at around -10% with the exception of Great Britain (-36.96%).

**GY:** all Asian countries plus USA and other EU countries show a water saving effect due to an increase in water efficiency of 10% or more, up to 25% (Australia). The main exceptions are Spain, Russia and Germany (-9.67%). Great Britain is country with the greatest negative impact of $\Theta_{TECH}$ (-36%) while China, Brazil and Australia present positive values.

# 6 Network Analysis of Virtual Water Flows

In order to assess the spatial distribution of water, making comparable the Network analysis with I-O, we build the matrix $\Omega$ and $\Phi$, both containing the amount of direct virtual water exchanged for the intermediate and for the final goods, respectively:

$$\Omega = \hat{v} \cdot Z \tag{18}$$

and

$$\Phi = \hat{v} \cdot F \tag{19}$$

where F is a 1435x41 matrix which columns show the distribution of the final demand (domestic and import) of each country. Since v is the water intensity vector, the row sum of both matrices should return the total amount of water used in each sector: $\Omega \cdot i + \Phi \cdot i =$ w. We investigate the Directed and Weighted[9] Graph of the actual exchanges, among the sectors of all the countries, of water embedded in each product. In this way it is possible to integrate the water trade balance analysis which only gives the aggregate water consumption of each country, without any information about the linkages among them.

Each combination of country-sector pair is represented by a node of the Network. Links between nodes are directed on the basis of the flow of trade, e.g. from exporter to the importer, and are weighted by the volume of virtual water traded. In particular, we present results only for matrix $\Omega$, assessing the topological structure of intermediate trade, giving a better understanding of the technological evolution and its spatial distribution. In our case $\Omega$ is the weighted adjacency matrix whose elements $\omega_{ij}$ represent the edge due to the link between node i and j, that is the flow of water that comes from i to j. Strictly-positive self loops $\omega_{ii} >0$ capture the idea of a sector using its own product as input. Directed networks are typically asymmetric, meaning that $\omega_{ij} \neq \omega_{ji}$, so we need to recover the information both from the importer and the exporter side. We define $k_{in_i}$ the in-node degree, that is the number of sectors that are exporting to sector i; while $k_{inS_i} = \Sigma_j \omega_{ij}$ is the in-node strength of node i, that is the total amount of purchasing of sector i[10]. Symmetrically we can define the out-node degree $k_{out_i}$ and strength $k_{oS_i}$ of node i by summing the entries in the row i of the adjacency matrix.

Here we are dealing with the issue to choose the level of aggregation of the analysis. Results are quite robust and they do not differ significantly when we consider all the sectors disaggregated or even when we aggregate by considering only 5 macro-sectors[11]. The outcomes below refer to the Graph composed by 40x35 nodes[12], each of which trades virtual water[13]. We remove the ROW because, by definition, it includes a great variety of countries, and then it does not represent an homogeneous entity. The topological structure is not affected by that, with the exception of the ranking because ROW covers a big share of the virtual water globally traded. In what follows we describe some statistics of interest (assortativity, degree distribution and Page-Rank) for the whole graph, while in the last part we apply an higher level of aggregation in order to show the evolution of the community structure of VWT.

Table 3 shows some statistics of interest whose give important information about the topological structure of the Network.

We observe a great increase in the volume of VWT for each kind of water, although their percentage with the respect of the total water consumed is almost constant, covering about half of the global volume for B and GY, and less than 40% in case of GN. Although the number of edges (or links) is quite large, the share of active linkages, with the respect to all possible combinations ($1400^2$), is very low, covering at most the 7% in case of B and GY, and less than 2% in case of GN. This is not surprising because we are dealing only with the direct VWT, and many sectors are characterized by a water intensity coefficient of zero.

[9]We filter the edges such that the minimum amount of virtual water traded is 1000 $m^3$. This simplifies the computation without affecting the results.

[10]This computation reminds the backward linkage index which returns the column sum of the Leontief matrix to assess the importance of a node.

[11]Consistently with Section 2 we consider: AFF, Fd, EWG, DUS and Others.

[12]The number of countries is 40 each of which is composed by 35 sectors.

[13]Self-loops are allowed, since that they represent the domestic trade.

Table 3: Fundamental properties of VWT Network for intermediate goods.

| $\Omega$ | $B_{1995}$ | $B_{2001}$ | $B_{2009}$ | $GN_{1995}$ | $GN_{2001}$ | $GN_{2009}$ | $GY_{1995}$ | $GY_{2001}$ | $GY_{2009}$ |
|---|---|---|---|---|---|---|---|---|---|
| VWT $Km^3$ | 621.05 | 655.48 | 829.25 | 2296.24 | 2469.83 | 3001.51 | 472.78 | 541.15 | 852.22 |
| VWT % | 41.00 | 41.07 | 42.72 | 38.41 | 36.91 | 37.12 | 50.06 | 49.94 | 56.52 |
| edges | 99864 | 110122 | 117595 | 30628 | 32429 | 33104 | 120527 | 134089 | 139220 |
| density | 5.10 | 5.62 | 6.00 | 1.56 | 1.65 | 1.69 | 6.15 | 6.84 | 7.10 |
| max($K_{in}$) | 238 | 243 | 241 | 40 | 40 | 40 | 226 | 230 | 223 |
| max($K_{od}$) | 1202 | 1237 | 1260 | 1254 | 1268 | 1264 | 1251 | 1257 | 1313 |
| max($K_{inS}$) $Km^3$ | 43.30 | 49.54 | 52.67 | 303.23 | 342.98 | 380.72 | 50.70 | 56.43 | 100.00 |
| max($K_{oS}$) $Km^3$ | 90.03 | 87.80 | 143.86 | 536.50 | 576.63 | 614.80 | 101.64 | 122.44 | 198.64 |
| $LogN_{inS}$: $\mu$ | 10.18 | 10.23 | 10.27 | 9.59 | 9.65 | 9.68 | 9.52 | 9.65 | 9.85 |
| ($\sigma$) | (2.84) | (2.90) | (2.85) | (3.27) | (3.28) | (3.33) | (2.69) | (2.72) | (2.77) |
| $LogN_{oS}$: $\mu$ | 9.99 | 10.09 | 10.19 | 16.19 | 16.19 | 16.27 | 10.59 | 10.72 | 10.82 |
| ($\sigma$) | (3.44) | (3.44) | (3.44) | (2.19) | (2.23) | (2.29) | (3.59) | (3.58) | (3.67) |
| FIT $k_{inS}$ vs $k_{in}$ | 2.38 | 2.42 | 2.41 | 3.53 | 3.54 | 3.48 | 2.58 | 2.68 | 2.81 |
| FIT $k_{oS}$ vs $k_{od}$ | 1.99 | 2.00 | 1.98 | 2.18 | 2.47 | 2.19 | 2.10 | 2.10 | 2.13 |
| $r^{\omega}_{i\to j}$ | 0.024 | 0.024 | 0.019 | 0.016 | 0.015 | 0.016 | 0.024 | 0.023 | 0.019 |

The link weight ranges from $1{\cdot}10^3$ $m^3$ to a maximum of $380{\cdot}10^9$ $m^3$ ($USA_{Fd}$) in case of in-node strength and of $615{\cdot}10^9$ $m^3$ ($USA_{AFF}$) in case of out-node strength, indicative of high link weight heterogeneity. Given the direction of the link we can list the main importers[14] (with $k_{inS}$) and exporters (with higher $k_{oS}$):

**B:** during the entire period the key importers remain the same, led by the Fd sector of USA which uses more than 50 $km^3$ of blue water. In any case the AFF and Fd sectors of USA, China and India cover alone about the 30% of the whole water usage. Amongst the main exporters we can confirm the key players found in the I-O analysis, with some interesting novelties. As expected the sector AFF of India, China and USA and the EWG sectors of China, Brazil, Canada, Russia and USA are always in the top positions. In 2009 they supply 455 $km^3$ of VW which represents almost the half of the B VWT for intermediate goods.

**GN:** Similar results hold also in this case. The Fd sector of USA, Brazil and China is always in the top 3 positions, whilst we find only the sector AFF among the exporters. This is not a surprise because it is the only one which has a positive water coefficient[15]. Again USA, China Brazil and India are the top exporter, supplying in 2009 the 65% (more than 1900 $km^3$) of the overall green water needed for the global production.

**G:** the main difference, as compared with B and GN, is the presence of the Metallurgical and Chemical sectors among the top out strength nodes, in particular China became the most important exporter, with almost 900 $km^3$. This finding is particulary interesting because it allows us to isolate and unravel the importance of each sector within the matrix Z without any reference to the final demand, by a simple assessment of direct virtual water link. Conversely, I-O assessment returns the marginal impact of each sector given an increase in the demand of each particular good (or product of a sector), then it requires information from the distribution and the growth of final demand.

Assortativity measures the similarity of connections in the graph with respect to the node strength, hence it is a correlation coefficient between the strengths (weighted degrees) of all nodes on two opposite ends of a link. A positive assortativity coefficient indicates that nodes tend to link to other nodes with the same or similar strength. This property was defined by Newman (2002) [20] and we calculate the weighted[16] version proposed in Leung and Chau (2007) [22] as:

$$r^{\omega}_{\delta\to\iota} = \frac{\frac{\sum_j \delta_j \cdot \iota_j}{H} - (\frac{\sum_j \delta j + \iota_j}{2H})^2}{\frac{(\sum_j \delta j^2 + \iota_j^2)}{2H} - (\frac{\sum_j \delta j + \iota_j}{2H})^2} \tag{20}$$

[14]Note that by including self-loops and intra-country trade, the terms import and export not necessary refer to transfers abroad but in most of the cases they are led by domestic exchanges.

[15]For each country i and each sector j $\neq$ AFF we have that $v_{ij} = 0$.

[16]The code is a modified version of what is given by MIT Strategic Engineering web site (http://strategic.mit.edu).

Table 4: Top 5 ranking of Pagerank for B, GN and GY: a comparison between 1995 and 2009.

| BLUE | | | | GREEN | | | | GREY | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | | 2009 | | 1995 | | 2009 | | 1995 | | 2009 | |
| CAN_EWG | 0.08 | CAN_EWG | 0.138 | BRA_AFF | 0.099 | BRA_AFF | 0.116 | RUS_CH | 0.081 | CHN_AFF | 0.061 |
| RUS_EWG | 0.049 | RUS_EWG | 0.039 | USA_AFF | 0.086 | USA_AFF | 0.083 | USA_AFF | 0.061 | CHN_Met | 0.057 |
| AUT_EWG | 0.045 | CHN_EWG | 0.039 | IND_AFF | 0.066 | HUN_AFF | 0.061 | RUS_Pp | 0.043 | USA_AFF | 0.054 |
| FRA_EWG | 0.036 | AUT_EWG | 0.039 | HUN_AFF | 0.042 | CAN_AFF | 0.047 | IND_AFF | 0.037 | CHN_CH | 0.043 |
| SWE_EWG | 0.036 | SWE_EWG | 0.035 | CAN_AFF | 0.042 | BGR_AFF | 0.039 | CHN_AFF | 0.034 | RUS_CH | 0.04 |

where H is the sum of the weighted edges of the Network and $\delta_j, \iota_j$ represents the out-node and in-node strength of the two vertices connected by the j$^{th}$ link. We compute the assortativity index for all the 4 possible combinations (out-out, in-in, in-out and out-in which we report), with very similar findings. The values is slightly positive, which is in accordance with the results of Dalin et al [8], who show that the disassortative behaviour breaks down when weights are taken into account, suggesting the existence of a weighted rich club: a subset of prominent nodes directed their strongest ties towards each other to a greater extent than randomly expected. This is a remarkable property which typically is observed in social network where nodes of the same degree (strength) tend to be linked with similar ones.

It is worth to investigate the distribution of in-node and out-node degrees and strength in order to assess the heterogeneity of the network connectivity. As expected we always observe that max($k_{oS}$) > max($k_{inS}$) because only few sectors are providing virtual water to all the others. We plot the natural logarithm of strength of the nodes as a function of their degree in Figure 5. We observe, with the exception of $k_{oS}$ of GN, a power law relationship that follows the form $k_{inS} \sim k_{in}^{\gamma}$ and $k_{oS} \sim k_{out}^{\zeta}$. Coefficients are reported in table 3. The power law $\gamma$ coefficient is relatively stable (less than 10% change) and of about 2.5 for B and GY, while it is larger than 3.5 for GN. The same holds also for $\zeta$ which in all the cases floats around 2, revealing a highly non-linear relationship, i.e. increasing the number of trading partners implies an increase in the VWT which is more than proportional. The distribution of both $k_{oS}$ and $k_{inS}$ seems to be fitted well by a lognormal[17] distribution (Figure 6). This results differ from the fat-tail behavior found in Konar et al. (2012) [17], mostly because here we are allowing self-loops and because we are not considering the VWT flows due to the exchanges of final goods, focusing only on the matrix $\Omega$. Given the time stability of the distributions, we show only fits for the last year (2009). Although these results hold only for a small set of countries, we would expect similar findings even in case in which more data and details for the ROW was available. In fact the system seems to remain stable at different levels of aggregation and the absence of the half of the VWT (represented by the ROW) does not affect the topology.

The policy implication might be to increase the number of trade partners in order to have an increase, more than proportional, in the availability of virtual water. On the other hand we may care not only about the efficiency of VWT but also about the global distribution given that the gap in water use per capita has increased in time.

Among the possible measures of centrality we decide to focus only on Pagerank [23] given that its computation is directly comparable with the Leontief measures. This index was firstly introduced in computer science to determine the web-page's relevance or importance. Let P=($\rho_{ij}$) be a square matrix of the same size of $\Omega$, such that its entries correspond to a probability normalized by the $k_{oS}$ of each node. The Pagerank $\pi_j$ of node j is recursively defined, in matrix notation, as $\pi_j = \pi_j \cdot$ H. As we can see it recalls eq. (6) in which we defined the Leontief inverse in order to solve the linear system which describes our economy.

Pagerank is a natural candidate, among indexes of centrality, to investigate shocks propagation both at economic and ecological level. Indeed, due to the intersector linkages, shocks to sectors (microeconomic level) that take the more central position in the I-O network could propagate to the whole economy (macroeconomic scale), translating into aggregate fluctuations with possible harmful effects on environment and economic systems. We rank the key nodes (in terms of $k_{oS}$) of intermediate goods by comparing the top 5 of 1995 and 2009 for all the three categories of water.

Pagerank returns a list of top exporter in line with previous findings, but with some interesting novelties, mostly for B water. Here in fact we observe only sector EWG among the top 5 mostly because it is highly connected with all the other sectors given its fundamental role in the production process. Moreover, it seems that also the ranking of countries is affected, with an increased importance of Canada and Russia. In case of GN

[17]We use the Kernel density smoothing function given in Matlab. It returns a probability density estimate, f, for the sample in the vector x. The estimate is based on a normal Kernel function, and is evaluated at 100 equally spaced points, xi, that cover the range of the data in x.

Figure 5: Plot of $k_{inS}$ against $k_{in}$ (left) and of $k_{oS}$ against $k_{out}$ (right).

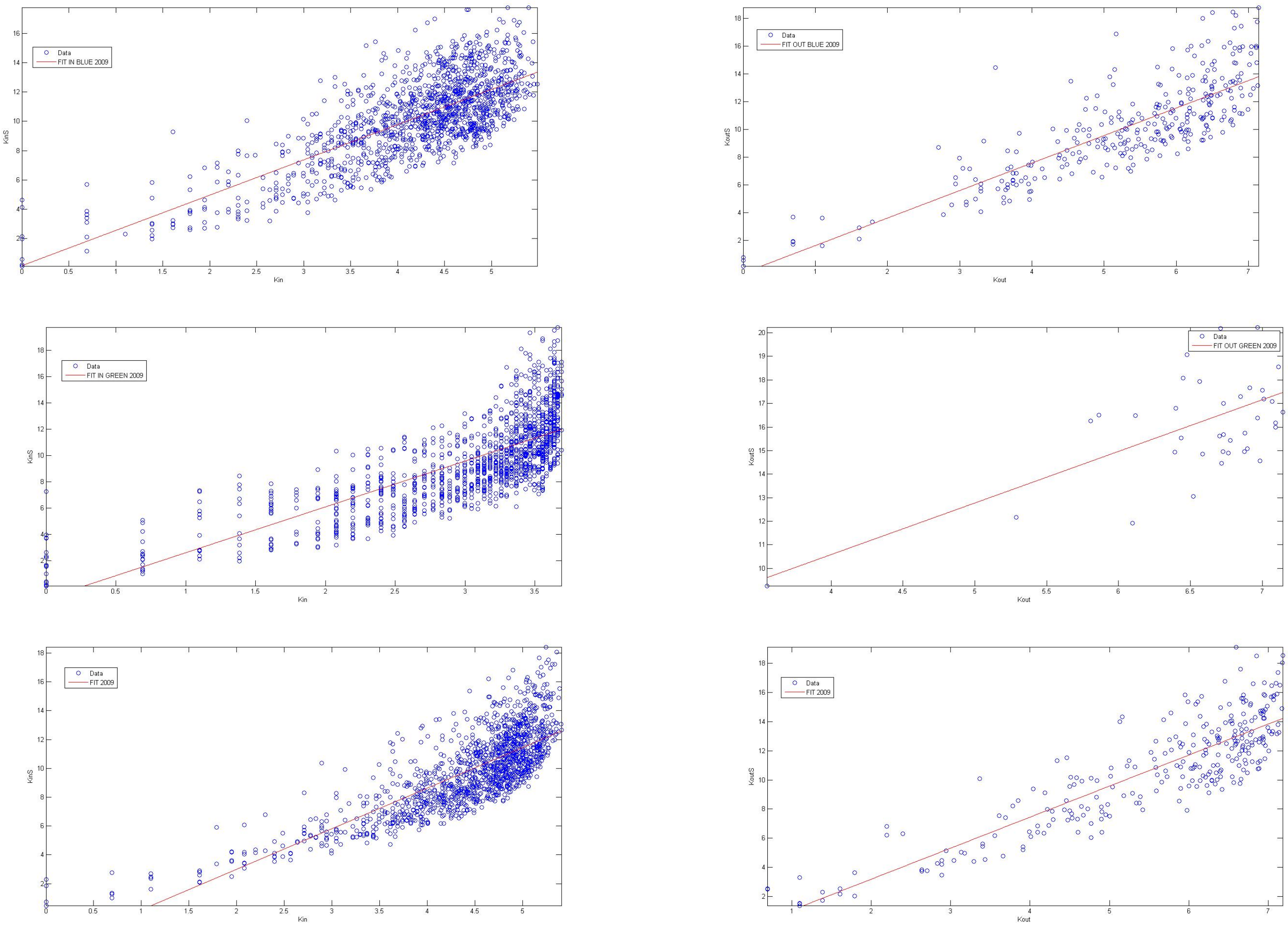
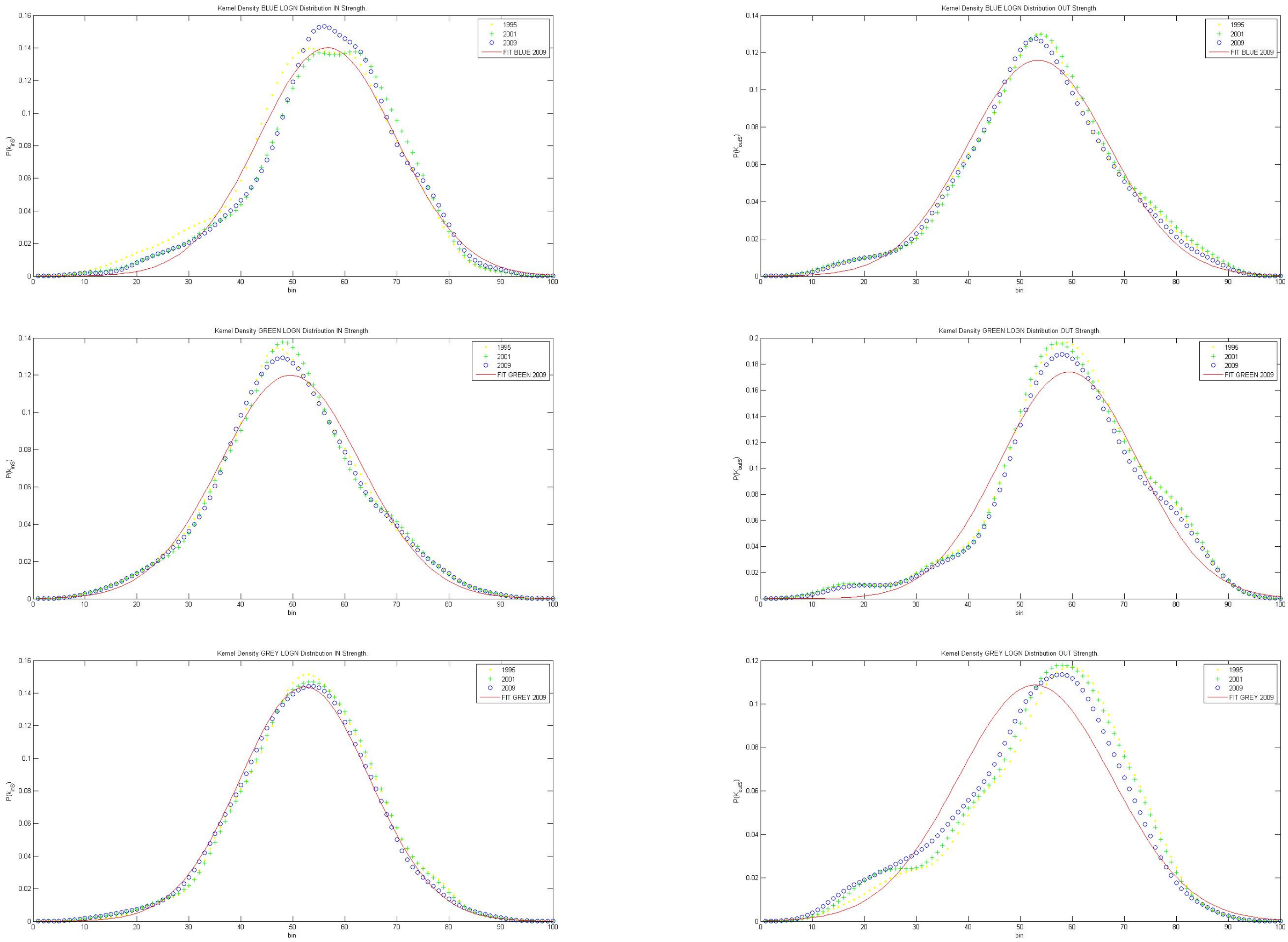


Figure 6: Kernel Density distribution of of $k_{inS}$ and $k_{oS}$.



and GY no big differences are found: the former is still led by Brazil and USA, while the latter is characterized by the increased importance of China.

### 6.1 Community Detection

Within the International Trade Network (ITN) literature we observe an increased interest in the attempt to study how the process of globalization is changing the topology and the spatial distribution of trade, in particular how and which "communities" of countries are emerging, with many edges connecting nodes in cluster. Following the recent paper of Zhen et al. (2014) [31], we apply the modularity optimization[18] introduced by Newman and Girvan [21], based on the idea that from a comparison between the density of the edges in a subgraph and that one would expect in a random graph (in which we would not have any communities), it is possible to detect cluster structures.

Given the big number of edges, we aggregate, without loss of coherence, some sectors of particular interest into 5 macro-sectors in order to have comparable results with the previous I-O analysis, in particular we consider: Agriculture, Hunting, Forestry and Fishing (AFF); Food, Beverages and Tobacco (Fd); Electricity, Gas and Water Supply (EWG); Textile, Chemicals, Metallurgic and Paper industries (DUS) and all the others gathered together (Othd). This simplification allows us to easily unravel the evolution of the connections among different sectors and their evolution over time. This new graph is composed by 200 nodes that trade both at domestic and international levels. In what follows we list the evolution in the emergence of community for each category of water, by comparing three years of interest: 1995, 2001 and 2009. Note that by allowing intranational trade, we can confirm that the domestic exchanges are the most important, although the emergence of international communities, that are not always explained by geographical proximity, is confirmed.

**B:** notwithstanding the globalization process we observe an increased tendency of bigger countries (USA, Japan, China, India and Brazil) to rely more on regional VWT than to create international communities. This might be explained by the fact that the domestic amount of virtual water traded is much larger than what they exchange with other countries. Moreover they are linked with many countries so they differentiate, without forming any significant cluster. Most communities were based on a single economy. USA and Japan created, in 1995, a "small community" with South Korea and Australia respectively, but afterwards these groups have disappeared. An opposite trend characterizes Canada and Germany that, in 2009, are among the key players of a big community which contains many European countries (Great Britain, Belgium and Austria among others). Figure 7 shows this big community in violet. Finally, we want to highlight two features observed: first, European countries tend to create more communities than other continents; second, the emergence of communities is not always explained by local proximity as the presence of Canada in an EU community demonstrates.

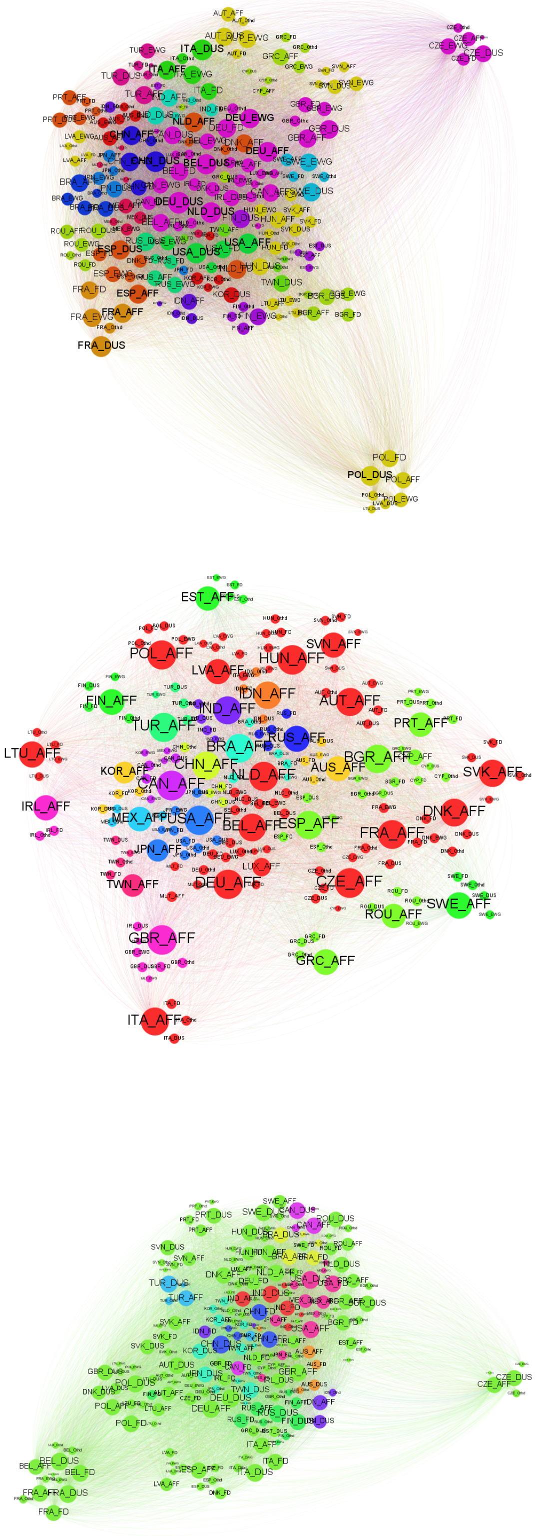
**GN:** in this case we observe a greater variability than in the previous case. Interesting is the behaviour of Russia which led a community formed by many eastern European countries in 2001, but during the following years it lost its key role. Outside Europe we find an interesting evolution of Japan that until 2001 was mostly linked to Australia and Korea, while in 2009 formed a small community with USA. It seems that for green water the geographical proximity is more important in explaining the emergence of communities.

**GY:** the European community has increased its size from 1995 to 2009 with Germany and Italy always among the most important in terms of VWT. Also here, Russia lost the leading role, covered in 1995, within the eastern European community. Japan is very volatile: in 1995 it was strictly linked to Canada, in 2001 it creates a community with Australia, Korea and Taiwan, while in 2009 it keeps its relation with South Korea and Taiwan only through the following sectors: DUS, Fd and Othd.

Figure 7 shows the graph which characterize VWT for intermediate goods in 2009. The size of each node is proportional to its node degree. As we have seen the community detection helps us to understand the emergence of linkages at the international level, providing further information about the effect of technological change. In particular it helps to define the source of variation (given by $\Theta_{TECH}$ and $\Theta_{IE}$) unravel through the SDA.

[18] It consists to optimize the function Q=$\frac{\sum_{ij}(A_{ij}-P_{ij})\delta(C_i,C_j)}{2m}$, where A is the adjacency matrix, P is the random graph with the same degree sequence of A, m is the total number of edges and the $\delta$ function returns zero in case if node i and j belonging to the same community.

Figure 7: Community Structure for Blue (top left), Green (top right) and Gray (bottom) in 2009.



## 7 Conclusions

In this paper we apply a novel conceptual framework to the study of global VWT. In particular our choice to integrate I-O and Network methodologies helps us to better understand the evolution in the distribution of virtual water. Water use and water footprint increased between 1995 and 2008 and for almost all the countries considered in the paper, the agricultural sector and the food and drink consumption categories result to be the largest water users. However when trade is considered, the distribution of water usage changes considerably: EU27, USA and Japan are net water importers and during the period they increased their water deficit in terms of B, GN and GY water. Rest of the world, Brazil, China and India are the largest water exporter. SDA allowed us to unravel the sources of these differences and their evolution over time. As expected the growth of VW consumption is mostly due to both population and economic (and consumption) growth, which require more water than what is saved through innovation and increasing efficiency. Moreover we show that, in order to assess the real responsibility of each country, it is important to retain lower levels of decomposition due to the heterogeneous impact of different sectors. The example of Russia clarifies this point: from its VWT balance, close to zero, we would state that it is neutral in terms of global footprint, but this is not the case. Indeed Russia shows big volumes of trade and virtual import of BW from the EWG and of GY from the DUS. On the other hand Russia is a big exporter of AFF products which compensate the virtual water imported. These results are important information that can be used both in the policy and in the scientific arena to quantify the water consumption and the water responsibility of countries.

Network theory allowed us to integrate the information provided by the I-O assessment. In particular we show the non-linear behavior in the relationship between in-node and out-node strength and degree which follows a power law. This finding has important implications for the trade policy of water-scarce countries looking to increase their water availability.

Results from connectivity and centrality measures, confirming previous studies, show the presence of a weighted rich club where a tightly cluster of country-sector pairs trade the majority of the water embedded in the intermediate goods. Finally Community Detection allowed us to integrate the results given by SDA unravelling the evolution of international trade of intermediate goods. The large number of nodes and edges comes form the sectoral level of aggregation we have chosen. It reveals the evolution of different kinds of communities, mostly within EU27 countries. However geographical proximity is not enough to explain this phenomenon, as the presence of Canada in the EU communities for blue water demonstrates.

Our findings show that the need of management of water scarcity requires the development of transboundary agreements and policies both at global and regional levels. This fact is particularly relevant for the EU members, which have strengthen their relationships over the past decades. We mention the Water Framework Directive (2000/60/EC) which sets the objective of achieving the 'good ecological status' of all water bodies in the EU (surface as well as groundwater) by 2015 and the strong recommendation of full cost recovery for water services including environmental and resource costs. Afterwards the CAP (Common Agricultural Policy) has had, along the decades of the 80's and 90's, a strong impact on water use because it encouraged irrigation expansion and intensification of irrigated crops through subsidies to larger production-coupled. Nowadays this system has changed through "decoupling" payments to farmers from production and requiring environmentally-friendly nature protection actions from farmers for getting the payments. Finally we recall the 2012 Blueprint to Safeguard Europe's as an important, albeit partial, step towards an integrated and sustainable path of water management. As stated by Vanham and Bidoglio (2013) [28] "*the concepts of water footprint and virtual water may be relevant in the implementation of the policy options identified by the Blueprint Water*". This empirical analysis, while interesting on its own right, provides a new point of view in the development of models to forecast resource sustainability and to help the management of resources.

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## References

[1] Allan, J.A. (1994):"Overall perspectives on countries and regions", in P. Rogers and P. Lydon, (Eds.), Water in the Arab World: Perspectives and prognoses, Harvard University Press, Cambridge, MA (1994),

pp. 65-100.

[2] Antonelli, M., Roson, R., Sartori, M. (2012): "Systemic Input-Output Computation of Green and Blue Virtual Water 'Flows' with an Illustration for the Mediterranean Region". Water Resources Management, 26:4133-4146.

[3] Arto, I., Andreoni, V., and Rueda-Cantuche, J.M. (2012): "Water Use, Water Footprint and Virtual Water Trade: a time series analysis of worldwide water demand". 20th IIOA Conference, Bratislava (Slovakia), June 2012.

[4] Barnaby, W. (2009): "Do nations go to war over water". Nature, 458:282-283.

[5] Bin Su, Ang, B.W. (2012): "Structural Decomposition Analysis applied to energy and emissions: aggregation issues", Economic System Research, 24(3):299-317.

[6] Copeland, B.R., Taylor, S.M. (2004): "Trade, Growth, and the Environment", Journal of Economic Literature, 42(1):7-71.

[7] Carr, J.A., D'Orrico, P., Laio, F., Ridolfi, L. (2013): "Recent History and Geography of Virtual Water Trade". PLoS ONE 8(2): e55825. doi:10.1371/journal.pone.0055825.

[8] Dalin, C., Konar, M., Hanasaki, N., Rinaldo, A., Rodriguez-Iturbe, I. (2012): "Evolution of the global VWT network". Proceedings of the National Academy of Sciences of the United States of America, 109(16):5989-5994.

[9] De Haan, M. (2001): "A structural decomposition analysis of pollution in the Netherlands". Economic Systems Research, 13:181-196.

[10] Dietzenbacher, E., Los, B. (1999): "Structural Decomposition Analysis with Dependent Determinants", Economic Systems Research, 10(4):307-324.

[11] D'Odorico, P., Laio, F., Ridolfi, L. (2010): "Does globalization of water reduce societal resilience to drought". Geophysical Research Letters, 37(13).

[12] D'Odorico, P., Carr, J., Laio, F., Ridolfi, L. (2012): "Spatial organization and drivers of the virtual water trade: A community-structure analysis". Environmental Research Letters, 7.

[13] Gabaix, X. (2009): "Power Laws in Economics and Finance". Annual Review of Economics, 1:255-93.

[14] Hoekstra, A., Chapagain, A.K. (2008): "Globalization of water: Sharing the planet's freshwater resources". Blackwell Publishing, Oxford, UK.

[15] Hoekstra, A., Chapagain, A., Aldaya, M., Mekonnen, M. (2011): "The Water Footprint assessment manual. Setting the global standard", Earthscan, London and Washington.

[16] Hoekstra, A.Y., Hung, P.Q., (2002): "Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade". Value of Water Research Report Series No. 16, UNESCO-IHE, Delft, The Netherlands.

[17] Konar, M., Dalin, C., Suweis, S., Hanasaki, N., Rinaldo, A. (2011): "Water for food: The global virtual water trade network". Water Resources Research, 47.

[18] Miller R., Blair P. (2009): "Input-Output Analysis. Foundation and Extensions.", Cambridge University Press, Second Edition.

[19] Mubako, S., Lahiri, S., Lant, C. (2013): "Input-output analysis of virtual water transfers: Case study of California and Illinois". Ecological Economics, 93:230-238.

[20] Newman, M. (2002): "Assortative mixing in networks". Physical Review Letters, 89(20):208701.

[21] Newman, M., Girvan, M. (2004): "Finding and evaluating community structure in networks". Physical Review E, 69(2): 026113.

[22] Leung, C. , Chau, F. (2007): "Weighted Assortative And Disassortative Networks Model". Physica A: Statistical Mechanics and its Applications, 378(2):591-602.

[23] Page, L., Brin, S., Motwami, R., Winograd, T. (1999): "The pagerank citation ranking: bringing order to the web", Technical Report, Computer Science Department, Stanford University.

[24] Rees, W.E. (1992): "Ecological footprints and appropriated carrying capacity: what urban economics leaves out". Environment and Urbanisation, 4(2):121-130.

[25] Reimer, J.J. (2012): "On the economics of virtual water trade". Ecological Economics 75:135-139.

[26] Schade, C., Pimentel, D. (2010): "Population crash: prospects for famine in the twenty-first century". Environment, Development and Sustainability, 12:245-262.

[27] Turner, K., Lenzen, K., Wiedmann, T., Barrett J. (2007): "Examining the Global Environmental Impact of Regional Consumption Activities- Part 1: A Technical Note on Combining Input-Output and Ecological Footprint Analysis". Ecological Economics, 61:6-10.

[28] Vanham, D., Bidoglio, G. (2013): "A review on the indicator water footprint for the EU28", Elsevier, Ecological Indicators 26:61-75.

[29] Wiedmann, T., Lenzen, M., Turner, K., Barrett, J.(2007): "Examining the Global Environmental Impact of Regional Consumption Activities- Part 2: Review of input-output models for the assessment of environmental impacts embodied in trade". Ecological Economics, 61(1):15-26.

[30] Wilting, H., Hoekstra, R. Schenau, S. (2006): "Emissions and Trade: a Structural Decomposition Analysis for the Netherlands". mimeo.

[31] Zhu, Z., Cerina, F., Chessa, A., Caldarelli, G., Riccaboni, M. (2014): "The rise of China in the International Trade Network: A community Core Detection Approach". arXiv:1404.6950vl.

Table 5: Global Water Trade Balance: 1995, 2001 and 2009.

| | Blue water | | | Green water | | | Grey water | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1995 | 2001 | 2009 | 1995 | 2001 | 2009 | 1995 | 2001 | 2009 |
| AUS | 2.89 | 4.94 | -2.11 | 32.09 | 43.50 | 15.58 | 0.26 | 0.76 | -4.91 |
| AUT | -0.03 | 0.21 | 1.04 | -6.96 | -6.53 | -8.24 | -1.41 | -1.54 | -2.47 |
| BEL | -2.88 | -4.13 | -4.96 | -10.88 | -13.74 | -20.11 | -0.67 | -0.43 | -1.73 |
| BGR | 0.16 | 0.09 | 0.05 | 3.25 | 2.54 | 6.87 | 1.93 | 1.40 | 1.97 |
| BRA | 1.55 | 5.65 | 7.01 | 42.56 | 99.73 | 134.89 | 0.76 | 3.31 | 1.92 |
| CAN | 18.80 | 21.88 | 12.78 | 34.61 | 20.10 | 23.48 | 6.80 | 6.51 | 2.40 |
| CHN | 20.87 | 15.67 | 55.58 | 51.51 | 14.40 | 11.44 | 32.21 | 32.80 | 132.22 |
| CYP | 0.00 | -0.12 | -0.15 | -0.32 | -0.66 | -0.91 | -0.12 | -0.15 | -0.21 |
| CZE | -0.74 | -1.06 | -1.29 | -0.06 | -0.60 | -1.11 | 0.20 | 0.06 | -0.42 |
| DEU | -19.42 | -19.43 | -21.55 | -78.02 | -73.42 | -80.28 | -13.34 | -12.28 | -18.54 |
| DNK | -1.47 | -1.36 | -1.48 | -2.05 | -1.60 | -1.93 | -0.38 | -0.29 | -0.72 |
| ESP | -2.78 | -0.68 | -2.46 | -20.25 | -16.39 | -23.27 | -2.93 | -3.33 | -6.94 |
| EST | -0.08 | -0.19 | -0.18 | 1.16 | 0.38 | 1.49 | 0.04 | -0.07 | 0.09 |
| FIN | -0.24 | -0.50 | -0.74 | -1.72 | -2.48 | -4.00 | -0.47 | -0.53 | -1.15 |
| FRA | -6.33 | -6.67 | -9.07 | -22.83 | -27.41 | -28.69 | -3.56 | -3.72 | -7.40 |
| GBR | -10.68 | -14.07 | -15.46 | -38.10 | -54.55 | -61.97 | -7.07 | -10.65 | -14.01 |
| GRC | -0.61 | -1.17 | -1.66 | -3.55 | -4.85 | -8.31 | -0.93 | -1.32 | -2.32 |
| HUN | -0.54 | -0.89 | -0.79 | 4.93 | 4.00 | 7.54 | 1.42 | 1.17 | 1.51 |
| IDN | -0.66 | -0.88 | -2.16 | 20.97 | 29.57 | 34.36 | 0.20 | 0.72 | -1.37 |
| IND | 17.09 | 20.64 | 15.47 | 45.96 | 53.28 | 28.32 | 10.16 | 13.31 | 11.08 |
| IRL | -0.31 | -0.61 | -1.29 | 0.70 | -0.91 | -2.83 | -0.18 | -0.42 | -1.05 |
| ITA | -7.84 | -9.02 | -8.74 | -30.67 | -35.47 | -39.05 | -4.68 | -5.96 | -9.05 |
| JPN | -31.66 | -25.21 | -23.02 | -169.54 | -138.08 | -121.32 | -28.65 | -23.50 | -28.05 |
| KOR | -6.86 | -6.44 | -7.42 | -30.14 | -27.80 | -30.54 | -5.66 | -5.40 | -8.30 |
| LTU | -0.16 | -0.31 | -0.36 | 2.17 | 1.45 | 4.06 | -0.08 | -0.17 | -0.29 |
| LUX | -0.28 | -0.23 | -0.24 | -0.55 | -0.54 | -0.74 | -0.11 | -0.15 | -0.24 |
| LVA | 0.02 | -0.04 | -0.04 | 0.42 | 0.02 | 0.35 | 0.01 | -0.06 | -0.01 |
| MEX | 0.48 | -3.46 | -3.21 | 3.33 | -15.16 | -15.18 | -0.60 | -4.23 | -5.79 |
| MLT | -0.07 | -0.09 | -0.09 | -0.32 | -0.39 | -0.42 | -0.06 | -0.07 | -0.10 |
| NLD | -4.95 | -5.45 | -5.93 | -20.47 | -25.97 | -28.75 | -3.52 | -4.06 | -5.67 |
| POL | -0.88 | -1.97 | -2.27 | 2.48 | -1.28 | 1.00 | 1.71 | 1.38 | 3.55 |
| PRT | -0.79 | -1.14 | -1.16 | -5.94 | -7.68 | -6.59 | -0.66 | -0.98 | -1.13 |
| ROU | 0.64 | 0.39 | -0.08 | 1.84 | 0.80 | -0.56 | 0.57 | 0.90 | -0.08 |
| RUS | 6.86 | 13.39 | -1.37 | -2.35 | 9.62 | -55.32 | 4.91 | 9.56 | -1.22 |
| SVK | 0.01 | -0.09 | -0.59 | 0.21 | -0.40 | -2.32 | -0.01 | -0.14 | -0.66 |
| SVN | -0.10 | -0.03 | -0.14 | -1.37 | -1.28 | -1.99 | -0.02 | 0.05 | -0.05 |
| SWE | 1.37 | 1.94 | 1.21 | -5.00 | -5.52 | -6.70 | -0.86 | -0.97 | -1.64 |
| TUR | 0.92 | 0.80 | -0.47 | 0.89 | 4.38 | -6.48 | -0.48 | 0.35 | -1.84 |
| TWN | -2.66 | -2.75 | -1.77 | -11.54 | -12.89 | -8.58 | -1.55 | -1.32 | 1.46 |
| USA | -27.27 | -56.60 | -40.05 | -35.34 | -130.23 | -70.18 | -4.13 | -28.45 | -32.16 |
| ROW | 58.66 | 79.01 | 69.18 | 248.89 | 322.08 | 367.01 | 20.97 | 37.91 | 3.32 |

Table 6: Global Water Trade Balance ($km^3$) by sector: 1995, 2001 and 2009.

| | | 1995 | | | 2001 | | | 2009 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| COUNTRY | SECT | B | GN | GY | B | GN | GY | B | GN | GY |
| AUS | AFF | 3.75 | 32.09 | 1.45 | 5.94 | 43.50 | 2.35 | 0.65 | 15.58 | -0.55 |
| | EWG | -0.75 | 0.00 | 0.00 | -0.88 | 0.00 | 0.00 | -2.39 | 0.00 | 0.00 |
| | DUS | -0.10 | 0.00 | -1.19 | -0.13 | 0.00 | -1.59 | -0.35 | 0.00 | -4.35 |
| | Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 |
| BRA | AFF | -0.59 | 42.56 | 0.86 | 1.14 | 99.73 | 3.63 | 1.57 | 134.89 | 4.48 |
| | EWG | 2.20 | 0.00 | 0.00 | 4.56 | 0.00 | 0.00 | 5.67 | 0.00 | 0.00 |
| | DUS | -0.05 | 0.00 | -0.10 | -0.06 | 0.00 | -0.32 | -0.25 | 0.00 | -2.57 |
| | Other | -0.01 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 |
| CAN | AFF | -2.44 | 34.61 | 4.79 | -3.51 | 20.10 | 4.25 | -5.04 | 23.48 | 3.38 |
| | EWG | 20.77 | 0.00 | 0.00 | 24.77 | 0.00 | 0.00 | 17.55 | 0.00 | 0.00 |
| | DUS | 0.48 | 0.00 | 2.01 | 0.63 | 0.00 | 2.25 | 0.31 | 0.00 | -0.98 |
| | Other | -0.02 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | -0.04 | 0.00 | 0.00 |
| CHN | AFF | 12.68 | 51.51 | 22.69 | 6.13 | 14.40 | 18.49 | 13.13 | 11.44 | 50.68 |
| | EWG | 7.48 | 0.00 | 0.00 | 8.46 | 0.00 | 0.00 | 36.14 | 0.00 | 0.00 |
| | DUS | 0.70 | 0.00 | 9.52 | 1.06 | 0.00 | 14.31 | 6.18 | 0.00 | 81.54 |
| | Other | 0.02 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.13 | 0.00 | 0.00 |
| DEU | AFF | -10.90 | -78.02 | -6.90 | -9.90 | -73.42 | -4.99 | -10.91 | -80.28 | -6.71 |
| | EWG | -8.43 | 0.00 | 0.00 | -9.64 | 0.00 | 0.00 | -10.50 | 0.00 | 0.00 |
| | DUS | -0.03 | 0.00 | -6.44 | 0.17 | 0.00 | -7.30 | -0.07 | 0.00 | -11.83 |
| | Other | -0.06 | 0.00 | 0.00 | -0.06 | 0.00 | 0.00 | -0.08 | 0.00 | 0.00 |
| GBR | AFF | -5.80 | -38.10 | -3.52 | -7.51 | -54.55 | -5.04 | -8.95 | -61.97 | -7.06 |
| | EWG | -4.57 | 0.00 | 0.00 | -6.01 | 0.00 | 0.00 | -5.87 | 0.00 | 0.00 |
| | DUS | -0.29 | 0.00 | -3.55 | -0.51 | 0.00 | -5.61 | -0.58 | 0.00 | -6.95 |
| | Other | -0.02 | 0.00 | 0.00 | -0.04 | 0.00 | 0.00 | -0.06 | 0.00 | 0.00 |
| IND | AFF | 15.64 | 45.96 | 6.47 | 19.88 | 53.28 | 8.18 | 15.92 | 28.32 | 4.83 |
| | EWG | 1.30 | 0.00 | 0.00 | 0.54 | 0.00 | 0.00 | -0.61 | 0.00 | 0.00 |
| | DUS | 0.16 | 0.00 | 3.69 | 0.22 | 0.00 | 5.13 | 0.16 | 0.00 | 6.26 |
| | Other | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ITA | AFF | -4.11 | -30.67 | -2.84 | -4.31 | -35.47 | -2.87 | -4.50 | -39.05 | -4.26 |
| | EWG | -3.60 | 0.00 | 0.00 | -4.48 | 0.00 | 0.00 | -3.84 | 0.00 | 0.00 |
| | DUS | -0.11 | 0.00 | -1.84 | -0.22 | 0.00 | -3.10 | -0.38 | 0.00 | -4.80 |
| | Other | -0.01 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | -0.02 | 0.00 | 0.00 |
| JPN | AFF | -22.21 | -169.54 | -21.91 | -16.77 | -138.08 | -16.24 | -14.55 | -121.32 | -17.21 |
| | EWG | -8.71 | 0.00 | 0.00 | -7.73 | 0.00 | 0.00 | -7.54 | 0.00 | 0.00 |
| | DUS | -0.60 | 0.00 | -6.74 | -0.59 | 0.00 | -7.26 | -0.82 | 0.00 | -10.84 |
| | Other | -0.15 | 0.00 | 0.00 | -0.12 | 0.00 | 0.00 | -0.12 | 0.00 | 0.00 |
| RUS | AFF | -2.48 | -2.35 | -1.68 | -2.03 | 9.62 | -0.74 | -10.29 | -55.32 | -6.21 |
| | EWG | 9.09 | 0.00 | 0.00 | 14.96 | 0.00 | 0.00 | 8.86 | 0.00 | 0.00 |
| | DUS | 0.28 | 0.00 | 6.60 | 0.47 | 0.00 | 10.30 | 0.06 | 0.00 | 4.98 |
| | Other | -0.03 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 | -0.01 | 0.00 | 0.00 |
| USA | AFF | -4.80 | -35.34 | 3.75 | -15.81 | -130.23 | -6.30 | -8.34 | -70.18 | 0.13 |
| | EWG | -22.61 | 0.00 | 0.00 | -39.50 | 0.00 | 0.00 | -29.95 | 0.00 | 0.00 |
| | DUS | -0.05 | 0.00 | -7.88 | -1.39 | 0.00 | -22.15 | -1.89 | 0.00 | -32.28 |
| | Other | 0.19 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 | 0.13 | 0.00 | 0.00 |

Table 7: Additive SDA: from 1995 to 2009.

| | △ Blue (2009-1995) | | | | | △ Green (2009-1995) | | | | | △ Grey (2009-1995) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IE % | TECH % | SIZE % | △ % | △ (Km3) | IE % | TECH % | SIZE % | △ % | △ (Km3) | IE % | TECH % | SIZE % | △ % | △ (Km3) |
| AUS | -46.4 | -9.3 | 41.9 | -13.8 | -2.2 | -28.3 | 3.0 | 42.4 | 17.1 | 16.4 | -24.5 | 2.9 | 42.3 | 20.7 | 1.3 |
| AUT | -84.6 | 59.3 | 34.0 | 8.7 | 0.8 | 2.9 | -8.4 | 8.7 | 3.2 | 0.2 | 3.3 | -6.2 | 13.3 | 10.5 | 0.1 |
| BEL | -1.9 | -15.5 | 19.9 | 2.5 | 0.0 | 10.2 | -17.4 | 10.6 | 3.4 | 0.1 | 4.4 | -15.1 | 26.6 | 16.0 | 0.4 |
| BGR | -54.7 | 41.2 | 27.7 | 14.1 | 0.2 | -20.4 | 35.0 | -18.1 | -3.5 | -0.6 | -1.0 | 4.0 | -6.5 | -3.4 | -0.2 |
| BRA | 3.1 | 9.4 | 38.5 | 51.0 | 38.0 | -16.7 | 25.4 | 48.0 | 56.8 | 213.0 | -10.5 | 16.1 | 44.0 | 49.6 | 10.4 |
| CAN | -14.2 | -12.1 | 35.3 | 8.9 | 7.7 | -6.1 | -8.4 | 38.5 | 24.0 | 29.4 | 4.1 | -6.1 | 43.7 | 41.7 | 9.9 |
| CHN | -61.0 | 22.9 | 116.5 | 78.4 | 138.4 | -35.0 | -12.4 | 78.9 | 31.5 | 200.8 | -18.0 | 15.5 | 128.2 | 125.7 | 298.9 |
| CYP | -48.8 | 2.0 | -9.1 | -55.9 | -0.2 | -26.8 | 2.2 | -13.2 | -37.7 | -0.3 | -48.3 | 1.6 | -7.8 | -54.4 | 0.0 |
| CZE | -0.9 | -29.0 | 41.3 | 11.4 | 0.1 | -9.1 | -4.8 | 24.9 | 10.9 | 1.1 | 1.8 | -4.2 | 27.4 | 24.9 | 0.6 |
| DEU | -36.1 | 7.5 | 19.7 | -8.8 | -0.7 | 6.8 | -3.0 | 18.2 | 22.1 | 8.1 | 9.7 | -5.0 | 18.6 | 23.3 | 2.6 |
| DNK | -9.0 | 1.1 | 14.8 | 6.9 | 0.0 | -3.8 | 3.1 | 13.6 | 12.9 | 1.0 | -2.7 | 2.8 | 13.3 | 13.4 | 0.2 |
| ESP | -11.7 | 15.5 | 47.1 | 50.9 | 7.4 | 43.2 | -5.4 | 42.5 | 80.4 | 26.7 | 5.1 | -5.6 | 39.2 | 38.7 | 2.0 |
| EST | -10.8 | -10.3 | 37.2 | 16.2 | 0.0 | 15.2 | -4.9 | 58.3 | 68.5 | 1.7 | 75.2 | 1.0 | 67.5 | 143.6 | 0.3 |
| FIN | -20.8 | -13.8 | 33.0 | -1.6 | -0.1 | 7.4 | -7.3 | 18.3 | 18.5 | 1.0 | 3.4 | -19.3 | 32.8 | 16.9 | 0.1 |
| FRA | 10.3 | -22.3 | -1.4 | -13.5 | -3.0 | -31.1 | 13.9 | 37.7 | 20.5 | 12.5 | -15.4 | 10.8 | 44.7 | 40.2 | 4.5 |
| GBR | -3.5 | -22.6 | 21.4 | -4.8 | -0.1 | 9.1 | -36.6 | 29.0 | 1.5 | 0.3 | 12.6 | -36.7 | 28.6 | 4.5 | 0.2 |
| GRC | -12.7 | -42.7 | 45.6 | -9.8 | -0.5 | -4.3 | -57.1 | 46.0 | -15.4 | -1.9 | -2.5 | -55.4 | 45.4 | -12.4 | -0.1 |
| HUN | -25.5 | 22.6 | 6.3 | 3.4 | 0.0 | -46.3 | 59.2 | 1.2 | 14.1 | 2.9 | -39.9 | 35.4 | 3.9 | -0.7 | 0.0 |
| IDN | -35.2 | 13.3 | 49.6 | 27.6 | 3.8 | 12.3 | 3.6 | 48.8 | 64.8 | 166.9 | 11.7 | 3.6 | 47.8 | 63.1 | 12.0 |
| IND | -14.5 | -19.0 | 59.5 | 26.1 | 63.0 | -15.6 | -18.7 | 53.5 | 19.1 | 138.9 | -10.2 | -16.3 | 70.9 | 44.4 | 53.7 |
| IRL | -34.7 | 5.1 | 58.4 | 28.9 | 0.1 | 7.7 | -44.5 | 35.4 | -1.4 | -0.1 | -0.1 | -18.0 | 54.5 | 36.4 | 0.1 |
| ITA | 7.8 | -2.3 | 12.4 | 17.9 | 2.6 | -6.5 | -16.8 | 13.3 | -9.9 | -4.8 | -5.1 | -16.0 | 13.1 | -7.9 | -0.9 |
| JPN | -12.5 | -3.0 | 5.4 | -10.0 | -2.4 | -2.6 | -0.5 | -11.1 | -14.2 | -3.3 | -1.5 | -14.8 | -2.0 | -18.3 | -1.4 |
| KOR | -43.4 | 28.3 | 29.3 | 14.3 | 0.3 | -13.3 | 29.3 | -11.0 | 4.9 | 0.7 | -10.1 | 22.7 | 9.5 | 22.1 | 0.4 |
| LTU | -23.9 | -26.2 | 49.4 | -0.6 | 0.0 | 32.9 | -25.0 | 79.5 | 87.3 | 6.1 | 66.0 | -17.3 | 86.2 | 134.9 | 0.2 |
| LUX | -65.5 | 36.0 | 45.1 | 15.6 | 0.0 | 19.1 | -21.2 | 21.6 | 19.5 | 0.0 | 7.8 | -18.0 | 19.0 | 8.7 | 0.0 |
| LVA | 1.3 | -12.2 | 27.3 | 16.5 | 0.1 | 61.0 | 7.7 | 26.5 | 95.2 | 2.7 | 72.8 | 11.1 | 28.1 | 111.9 | 0.4 |
| MEX | -31.7 | -2.6 | 44.2 | 9.9 | 2.0 | -21.0 | -10.2 | 38.7 | 7.6 | 7.8 | -14.2 | -9.4 | 39.0 | 15.4 | 1.9 |
| MLT | -65.8 | 3.8 | 15.0 | -47.1 | 0.0 | -43.2 | 6.2 | 19.0 | -18.0 | 0.0 | -44.5 | 6.6 | 16.3 | -21.6 | 0.0 |
| NLD | -17.3 | -9.3 | 27.1 | 0.4 | 0.0 | -17.0 | -11.5 | 27.2 | -1.3 | -0.1 | -8.7 | -11.1 | 27.9 | 8.2 | 0.1 |
| POL | -10.5 | -11.6 | 73.6 | 51.4 | 0.7 | -16.5 | -28.4 | 48.3 | 3.4 | 1.6 | -16.4 | -8.7 | 73.7 | 48.6 | 5.2 |
| PRT | -66.2 | 25.1 | 27.8 | -13.3 | -0.6 | -32.4 | 7.6 | 5.9 | -19.0 | -2.1 | -32.4 | 5.6 | 7.4 | -19.5 | -0.2 |
| ROU | -6.1 | -42.9 | 44.5 | -4.5 | -0.2 | -16.2 | -18.5 | 20.8 | -14.0 | -5.7 | -5.5 | -4.2 | 55.6 | 45.9 | 2.4 |
| RUS | -7.9 | -18.3 | 35.3 | 9.2 | 5.1 | 8.6 | -18.6 | 48.6 | 38.6 | 116.2 | 4.0 | -12.8 | 52.6 | 43.8 | 19.8 |
| SVK | 18.9 | -70.8 | 42.4 | -9.5 | -0.1 | -39.7 | -12.9 | 51.2 | -1.4 | -0.1 | -23.1 | -14.2 | 52.7 | 15.4 | 0.1 |
| SVN | 23.0 | -6.2 | 26.1 | 42.9 | 0.4 | 4.7 | -10.7 | 1.4 | -4.6 | 0.0 | 12.4 | -7.6 | 14.1 | 18.9 | 0.2 |
| SWE | -11.9 | -10.2 | 18.7 | -3.3 | -0.6 | -11.4 | 11.5 | 8.4 | 8.5 | 0.6 | -7.0 | 7.6 | 12.5 | 13.1 | 0.2 |
| TUR | -63.6 | 17.4 | 54.4 | 8.2 | 1.9 | -10.6 | -0.6 | 23.1 | 11.9 | 9.2 | -3.6 | 11.2 | 34.2 | 41.8 | 4.1 |
| TWN | -14.3 | 2.6 | 19.6 | 7.9 | 0.5 | 12.7 | -4.9 | 9.2 | 17.0 | 5.5 | 49.3 | 0.2 | 30.3 | 79.8 | 5.2 |
| USA | -5.7 | -15.0 | 24.8 | 4.1 | 7.1 | 3.9 | -9.7 | 29.3 | 23.5 | 153.3 | 11.1 | -16.1 | 25.7 | 20.7 | 33.2 |
| ROW | -79.1 | 41.2 | 70.2 | 32.3 | 156.7 | -18.8 | 6.2 | 59.4 | 46.8 | 1003.2 | -12.4 | 4.9 | 58.7 | 51.2 | 95.9 |

Table 8: Sectoral classification in WIOD (based on Nace rev 1.1)

| ID | Description | Nace codes |
|---|---|---|
| AFF | Agriculture, Hunting, Forestry and Fishing | 01, 02, 05 |
| C | Mining and Quarrying | 10, 11, 12, 13, 14 |
| Fd | Food, Beverages and Tobacco | 15, 16 |
| Tx | Textiles and Textile Products | 17, 18 |
| 19 | Leather, Leather and Footwear | 19 |
| 20 | Wood and Products of Wood and Cork | 20 |
| Pp | Pulp, Paper, Paper , Printing and Publishing | 21, 22 |
| 23 | Coke, Refined Petroleum and Nuclear Fuel | 23 |
| CH | Chemicals and Chemical Products | 24 |
| 25 | Rubber and Plastics | 25 |
| OMet | Other Non-Metallic Mineral | 26 |
| Met | Basic Metals and Fabricated Metal | 27, 28 |
| 29 | Machinery, Nec | 29 |
| 30t33 | Electrical and Optical Equipment | 30, 31, 32, 33 |
| 34t35 | Transport Equipment | 34, 35 |
| 36t37 | Manufacturing, Nec; Recycling | 36, 37 |
| EWG | Electricity, Gas and Water Supply | 40, 41 |
| F | Construction | 45 |
| 50 | Sale, Maintenance and Repair of Motor Vehicles and Motorcycles | 50 |
| 51 | Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles | 51 |
| 52 | Retail Trade, Repair of Household Goods | 52 |
| H | Hotels and Restaurants | 55 |
| 60 | Other Inland Transport | 60 |
| 61 | Other Water Transport | 61 |
| 62 | Other Air Transport | 62 |
| 63 | Other Supporting and Auxiliary Transport Activities | 63 |
| 64 | Post and Telecommunications | 64 |
| J | Financial Intermediation | 65, 66, 67 |
| 70 | Real Estate Activities | 70 |
| 71t74 | Renting of Machinery and Equipment and Other Business Activities | 71, 72, 73, 74 |
| L | Public Admin and Defence; Compulsory Social Security | 75 |
| M | Education | 80 |
| N | Health and Social Work | 85 |
| O | Other Community, Social and Personal Services | 90, 91, 92, 93 |
| P | Private Households with Employed Persons | 95 |
| HH | Households | HH |

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