VIRTUAL WATER IN FOOD PRODUCTION AND GLOBAL TRADE

REVIEW OF METHODOLOGICAL ISSUES AND PRELIMINARY RESULTS

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INTRODUCTION

The water consumed in the production process of an agricultural or industrial product has been called the 'virtual water' contained in the product (Allan, 1998). If one country exports a water-intensive product to another country, it exports water in virtual form. In this way some countries support other countries in their water needs. For water-scarce countries it could be attractive to achieve water security by importing water-intensive products instead of producing all water-demanding products domestically (WWC, 1998). Reversibly, water-rich countries could profit from their abundance of water resources by producing water-intensive products for export. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic (Hoekstra and Hung, 2002). Virtual water trade between nations and even continents could thus ideally be used as an instrument to improve global water use efficiency, to achieve water security in water-poor regions of the world and to alleviate the constraints on environment by using best suited production sites (Turton, 2000).

Virtual water has not attracted much research so far. What are the volumes involved? Do these volumes represent a significant part of the blue or of the green water volumes used in agriculture? What are the current tendencies? Which are the countries exporting most of the virtual water and which are the ones that import it? Which are the products responsible for the most important transfers? There is even no clear methodology to evaluate the virtual water contents of food products.

An attempt was made to quantify these volumes. This paper presents results as well as preliminary comparisons with the results obtained by Hoekstra and Hung (2002). The method utilized is also presented and discussed. It should be pointed out that quantifying the volumes of virtual water is not straightforward because water productivity is variable in space and time. Thus, when assessing the virtual water traded between two countries, one can estimate either the water actually used by the country exporting the food product or the water saved by the country importing it. In many cases these transfers occur from high performing production sites to lower performing sites, which means that globally real water is saved (Oki, 2002). It has been estimated that not only Egypt saved 5.8 billions m3 of water from national allocation in 2000 through maize imports, i.e. about 10% of its annual allocation, but globally a saving of 2.7 billion m^3 of real water is generated thanks to the differential of productivity between maize exporting countries and Egypt (Renault, 2003).

These concepts have however not been used in the present work due to the amount of data needed to estimate these volumes. The perspective was more simply (i) to provide first estimates of the virtual water transfers based on a unique set of references and the relative share of different types of traded food products, and (ii) to identify the difficulties as well as important assumptions needed to compute virtual water volumes.

The first part of the paper looks at methodologies whereas the second part focuses on preliminary results on world assessment of water embedded in food products and of traded virtual water.

1. METHODOLOGICAL ISSUES

In this section an attempt is made to point out the methodological steps that need to be properly addressed when estimating virtual water in food consumption and in food trade. Aggregating virtual water content from crop water consumption at field level up to the global banquet is a path along which many assumptions must be made. Therefore the first rule if any in studies on virtual water is to clearly specify assumptions and accounting procedures used.

This section draws on recent studies made by the authors and lists some of the important points that one needs to bear in mind when assessing virtual water. This is a preliminary attempt to come up with comprehensive accounting procedures for virtual water budget. This section on methodologies is complementary to the set of principles proposed by Renault (2003) for assessing the value of virtual water.

Five major steps need to be considered:

- categorise food products with regards to processes and their virtual water value
- properly map the fluxes of products within and at boundaries of the system considered
- specify the production processes for each type of food product
- specify the scope of the study
- compute virtual water content and flows.

1.1. Characterising food products for Virtual Water studies

Almost all food products consume water as part of their production process, however the amount of water required per unit of production depends largely on the type of product. If the relationship between production and water consumption for instance through evapotranspiration, is often clear for crops, it can be quite fuzzy for other processes. This is why it is important to introduce some distinction in the food products, and sort them by pertinent criteria for virtual water content assessment.

1.1.1. Primary product

Cereals, vegetables and fruits fall into this category for which the relationship between water consumption and production is quite clear. Production (kg) and water evapotranspired (m3) are estimated at field level and are the basis of the virtual water value estimation (m3/kg), possibly adjusted with efficiency factors. These products are assessed as primary products even though sometimes transformed afterwards (e.g. fruit juice).

1.1.2. Processed products

These are the food items that are produced by processing primary products. Vegetal processed products include sugar (sugarcane, sugar beet), oil from various primary product, and alcoholic beverages.

1.1.3. Transformed products

Animal products must be considered as transformed products as their production using primary vegetal products (cereals, grass, other by-products).

1.1.4. By-products

These are food products which are produced by crops grown primarily for other purposes than their nutritional values. An example of by-product is cotton seed which is used to produce oil, while cotton is grown mainly for fibre production.

1.1.5. Multiple-products

Some agricultural products are grown not for one purpose but for many purposes. This is the case of coconut trees in South Asia, the products of which are used as materials for house building, raw material to produce sugar, coconut fruit, ropes, etc…. not including the environmental value of the perennial vegetation. In that case water consumption of the trees must be split into various uses of water, with no one being dominant. This is also the case for some animal production which goes beyond meat production (leather, offal, fat for industry, etc…).

1.1.6. Low or non water consumptive product

In this category, we find mainly seafood and sea fish for which no water consumption can be associated with their production. Inland fisheries can consume small quantities of water through water evaporation of natural streams and bodies, and sometimes through the vegetal primary products used to feed the fish.

We also find in this category some animal production which are fed by crop residues and various wastes from family consumption. For instance in China about 80 % of the pigmeat production (454 million heads) is of this type (backyard production). It is quite difficult to estimate the real water consumption for this type of products.

For this category, despite a low or nil real water consumption, an equivalent value of virtual water can be identified using the nutritional equivalence principle (Renault, 2003).

1. 2. Mapping the fluxes of products

As done for any other water accounting approach (e.g. hydrology at basin level) it is crucial to map the boundaries of the system under consideration, identify the fluxes and the stocks inside the system and at its boundaries.

To that end, it is important to dissociate primary and secondary products to account for stock variations and fluxes, for waste, seeds, and others uses (industrial). A simple illustration of this mapping is given in Fig.1.

One of the difficulties with processed product is to make sure that there is no duplication in the values utilized to ensure that a given quantity of water is not accounted for in different products. For instance, cereals used to feed cattle should not be counted twice, once in the cereal production and second in the meat production.

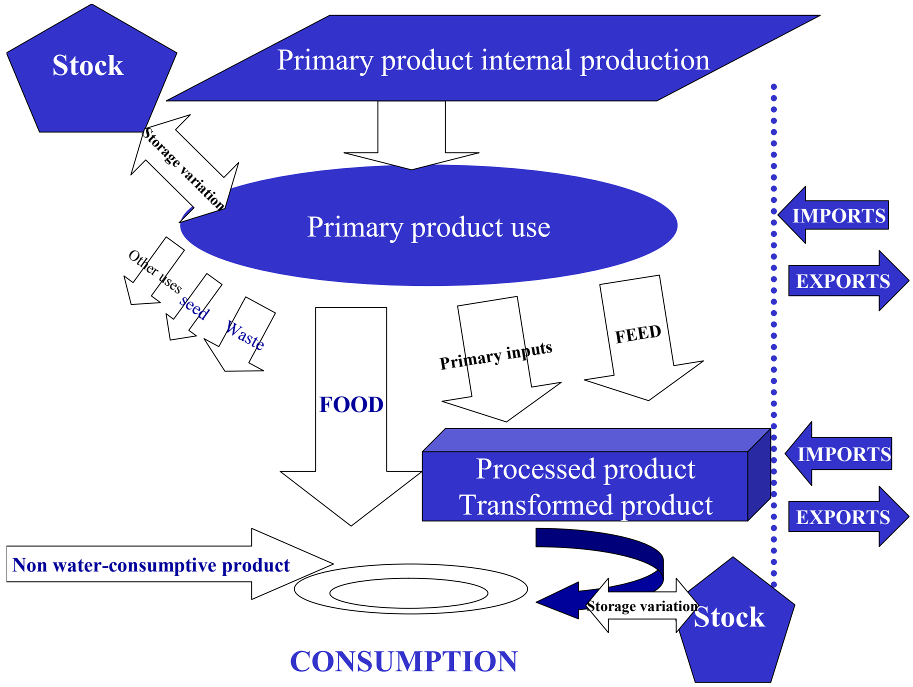

Figure 1. Mapping food product fluxes

1.3. <u>Specifying the efficiency of the processes</u>

It is important that for each product, the processes are well understood and that all components being accounted for. Although quite simple for annual crop production it can be more complex for perennial vegetation and processed products. The goal here is to lead to the best approximation of water consumption and food production.

In so doing at least three efficiencies must be considered.

- **Water efficiency**: In most studies on virtual water for food, the basic value of virtual water only considers the water evapotranspired at field level. However for irrigated agriculture, water losses either for the field application or during the distribution must be considered if there is no possibility of recycling these losses at basin level. It might be useful to introduce a correction coefficient to include them as proposed by Haddadin (2002). Furthermore water leaching sometimes required in arid areas to deal with saline water must also be considered as water consumption.
- **Production efficiency**: for multi annual food products the period and the level of production varies with time. The estimation of the virtual water value must take account total production and water consumption during life span. For instance for perennial vegetal products, or for dairy production, the effective period of production is reduced as compared to life span, and this must be considered as a reduced production efficiency compared to peak yields.
- **Consumption efficiency**: production at the farm gate does not entirely convert into consumption because of various wastes before reaching domestic consumption, and also the process itself of food consumption generates its own waste. This is particularly true for fresh products (vegetables fruits) which are sensitive for conservation.

As compared to virtual water, we must note that real water content in the final product (even for tomatoes) is always negligible, and so is water required by the transformation or processing of the products. Drinking water for a bull is less than 1% of the water requirements for feed (Barthelemy et al, 1993) and is not entirely a consumptive use.

1.4. Specifying the scope of the virtual water study

Assessing the embedded water content in food products at global level can be made by considering various options and serving various purposes. It is important that these options and purposes be clarified to avoid confusions.

Three options at least can be considered:

- Assessing real water requirements to produce the food needed at global level
- Assessing the value of virtual water in food consumption and in food trade
- Assessing the value of virtual water in trade policy and its impacts on water savings at national and global levels.

The procedures behind these three options might differ significantly as will be illustrated hereafter. Because some food products do not require water in their process or are produced from waste products, the real global water requirements are always lower than the total value of virtual water worldwide.

1.5. Computing virtual water content

The computations are made considering the different categories specified in 1.1.

1.5.1. Evaluating Virtual Water of primary products

The principle of calculation of water productivity is rather simple: crop water requirements ETa (m^3/ha) are calculated from the climatic demand (ET) adjusted with crop coefficients. Software like CROPWAT (FAO,1992) can be used for this purpose. Water productivity is then obtained by dividing the crop yield Y (kg/ha) by these crop water requirements. Virtual water value, the inverse of water productivity is then given by the following equation:

$$VWV = \frac{ETa}{Y} \tag{1}$$

1.5.2.Virtual water of transformed and processed products

The assessment of virtual water content of transformed and processed products pose specific problems linked to the yields of the processes utilized and to the fact that primary products may be used to produce various products. Animals are classified in this category and pose also difficulties due to the various allocations of their meat and by-products.

Vegetal transformation usually is made considering both a processing yield factor (kg of primary product amount to produce 1 kg of end product) and the Virtual Water Value of the primary product.

1.5.3. By-products

For this category, different methods of estimation of virtual water are possible:

- A first method consists in allocating virtual water of all sub-products proportionally to the quantities produced; for instance, each kg of cotton provides 0,625 kg of fibre and 0,375 kg of cotton seed and the water consumed is allocated proportionally to these values;
- A second method consists in allocating virtual water proportionally to the economic values of the various products. This second method may seems preferable but it has also some drawbacks: (i) the economic values may be quite variable in space and time; (ii) in case of by-products, the value may be very low because the product has little attract for the market and cannot be substituted to another product.
- A third method consists in dissociating the value from the real process, and to determine the value of virtual water by considering the **nutritional equivalence principle** (Renault, 2003). For instance in the case of cotton oil, it consists in affecting the value that is recorded for another oil product.

1.5.4. Multiple products and non water consumptive products

For these two last categories of products associating the food product to real water consumption is difficult. It is proposed to dissociate virtual water from the real process and estimate the virtual water value with the nutritional equivalence principle.

Regarding sea products and most of the fish (except inland fisheries), the production does not consume any water through evapotranspiration. Thus these products can be accounted for either with a nil virtual water value or with the virtual water content of other agricultural products by which they can be substituted. This is the assumption adopted here. With this assumption, virtual water value of sea food products and fish has been evaluated at 5 m3/kg with an equivalence based on alternative animal products equivalent for energy and proteins (Renault, 2003). As we will see hereafter, the share of sea food and fish products in virtual water trade is important (14%).

This method applies also for other transformed products, when accounting for primary product is difficult or pointless. Examples of that are cattle on grazing lands (not easy to account for grass) or backyard animal production such as pigs in China.

2. DATA AND METHOD USED.

2.1. Production, use and trade of food products

Various sources of data have been utilized:

(1) The annual food balance sheets from FAO were the major source of data: this data base contains information related to production, imports, exports and stock changes for most countries in the world. In addition, it also provides data related to the type of use of most food products; uses are split into the following categories: food, feed, seed, processing, waste and other uses. Data are available for the period 1961 to 1999.

(2) The TS database from USDA was also utilised mainly for comparison with the FAO data. TS database provides data related to production and trade of most crops all over the world. In most of the cases the data provided by the two sources compared very well as shown in Table 1. As a result whenever data where missing in the FAO database, they were taken from the TS database.

(3) A few data available in various publications were also utilized. In general these data confirmed that the FAO data were quite accurate.

Table 1. Comparison of a few data from FAO and TS data bases (in 10^3 T) (Year 1999)

	Products	**FAO data**			**TS database**		
		Production	Imports	Exports	Production	Imports	Exports
World	Wheat	585410	130483	134036	580674	125779	126927
	Palm oil	21019	14541	16181	21795	13991	14656
Asia	Wheat	259199	47987	7704	209511	28958	1946
	Palm oil	17768	8660	13858	18500	7869	13201
Egypt	Wheat	6347	6053	21	6350	5973	0
	Palm oil	0	561	0	0	455	0

In this study, we are using a set of data on virtual water values which have been estimated considering some of the exporting countries having high productivities. Most data are derived and adapted from the work of Barthelemy et al (1993) referencing mostly to the following countries: California, Egypt and Tunisia (See tables 1 & 2 in Appendix). Precise values of specific water demands had been derived for this purpose for several crops, processed and transformed products in California in 1990. Other values have been obtained from various papers or data bases.

The most important food products have been parameterized for this work. However, three types of products have not been accounted for in the calculations:

- Spices, coffee, cocoa and tea; these products should be included in future calculations;
- Fibre crops (e.g. cotton) have also not been included, but their side-products included in food chains have been included
- Grass production used to feed cattle has also not been considered.

<u>3. GLOBAL AND CONTINENTAL RESULTS</u>

3.1 <u>Principles</u>

The procedure utilized consisted in:

- For the global water requirements, estimating the use of water for primary vegetal products (table A1, appendix). In fact this was possible for most of the products except for a few oil products (coconut oil, palm oil, palmkernel oil and sesameseed oil) for which the production of raw products was not available in the data base. For these products, the virtual water content of the transformed products was utilized (table A2, appendix).

- Estimating the total content in virtual water of all products imported or exported by a country.

Using only the primary vegetal products leads to an underestimation of the total water utilized for food production for each country since some important products are not included (like grass).

Finally, since the specific water demands had been estimated for 1990, a correction factor was introduced to account for the increase in water productivity. Estimations were carried out using an annual increase in water productivity of 1 %.

3.2 Global values

A first estimate of virtual water budget and trade has been made at global scale using the approach presented above (Table 2).

Table 2. Water consumed for crop production and virtual water traded between countries at global scale for years1989, 1994 and 1999 assuming an annual increase of 1% in water productivity

	1989		1994		1999	
	Km^3/yr	$m^3/cap/yr$	km^3/yr	$m^3/cap/yr$	km^3/yr	$m^3/cap/yr$
Consumed water of cropped products	3569	697	3626	650	3777	632
Traded virtual water	1008	197	1111	199	1247	209
Ratio of traded virtual water vs consumed water	28%		31%		33%	

As compared to a total value of 5 200 km^3 (see hereafter), the order of magnitude of 3 700 km^3 of water embedded in food production seems correct if we recall the fact that only crops are considered (grass and natural pasture not included). This value compares also relatively well with the 3 800 km^3 of water resources mobilised as “blue water” and with the 1 800 km^3 of water consumed by irrigation (out of a total of 2 500 withdrawn; Cosgrove and Rijsberman, 2000).

Although based on a different set of data (since it includes many transformed products), the order of magnitude of the virtual water traded between countries seems also consistent with the total water volumes used for food production. The ratio of virtual water traded versus water consumed by cropped products represents about 30%. When comparing to the total value of 5 200 km3, this ratio is 23%. This undoubtedly has an impact on the management of water resources at global scale. It can also be noticed that the share of virtual water traded increases significantly with time, despite a decrease of values thanks to the increase of water productivity of 1%.

Finally, it should be pointed out that at global scale the water consumed by crop production represents about 2m^3/day/cap with a regularly decreasing trend[1].Since the cropped products per capita has remained constant during the period considered, the trend represents exactly a decline of 1% per year which correspond to the assumed annual increase in water productivity.

[1] Including the grasslands would result in a value close to 3 m^3/cap/day

3.3. Continental values

Using the continental values of the FAO database and the same method, a comparable estimation has been conducted. Results for 1999 are presented in the following tables in km^3/year (Table 3) and in m^3/cap/year (Table 4). Due to consistency problems in the data base, it has to be noted that for Europe, former Soviet Union Countries was excluded from the analysis.

Two continents, America and Oceania, are net exporters of virtual water. They represent 51% of the exported virtual water. In particular, the exports of Oceania are much more important than their own consumption. Two continents, Asia and Africa, are net importers of virtual water. They represent 46% of the imported virtual water. European Union occupies a specific place since it imports and exports high quantities of virtual water with a net balance almost equal to zero.

Table 3. Water consumed for crop production and virtual water traded from continents for year 1999, assuming an annual increase of 1% in water productivity. Values in km^3/year.

Continent	Water for crop production	Virtual Water imported	Virtual water exported	Net virtual water balance	Virtual water balance/ water for food (%)
North and Central America	684	164	317	-153	-22
European Union	386	384	377	7	2
South America	445	52	175	-123	-28
Asia	1673	426	182	244	15
Oceania	71	8	117	-109	-154
Africa	241	97	19	78	32

Table 4. Water consumed for crop production and virtual water traded from continents for year 1999, assuming an annual increase of 1% in water productivity. Values in m^3/cap/year except for (e).

Continent	Water for crop production (a)	Virtual Water imported (b)	Virtual water exported (c)	Net virtual water balance (d)=(b)-(c)	Consumption per day[(1)] (e)=(a°+(d)
North and Central America	1421	342	659	-317	3.0
European Union	1026	1020	1002	18	2.9
South America	1305	153	514	-361	2.6
Asia	436	118	50	68	1.4
Oceania	2345	281	3898	-3617	[(2)]
Africa	311	125	25	100	1.1

(1) this value excludes grass and other non cropped fodder products; (2) value meaningless without considering grass and non cropped fodder products

In terms of m^3/cap/year, the various data clearly show the inequality between continents although the figures here still neglect the use of grass and non crop fodder by cattle. North America and Europe use at least 3 m^3/cap/day of water to nourish their populations. South America is a bit lower with 2.6 m^3/cap/day. Asia and Africa lag behind with values respectively equal to 1.4 and 1.1m^3/cap/day respectively. Of course these values must still be corrected (in fact increased) but they clearly reveal already (1) the important needs of water for food and (2) the big inequalities between continents. If all continents would have adopted the same diet as the most developed countries, the total amount of water needed for the corresponding crop production would have been about 6 200km^3/year, i.e. a 74% more than the present situation. Most of this difference being due to Asia, it can be stated that Asia low water consumption for food production and the future evolutions of the diets of its inhabitants are very critical for the world water resources.

3.4. Comparison with other results

Hoekstra et Hung (2002) have computed virtual water values for crop products only, using a comparable method but actual crop yields per country obtained in FAO data base in 1999 combined with country estimations of crop water requirements. Their values are therefore country-specific and likely more precise but they do not include virtual water linked to transformed and processed products. It is thus expected that differences with our valued are rather important for countries which export significant amounts of transformed products.

Results for the following countries were compared: Egypt, Ethiopia, Nigeria, India, Indonesia, Pakistan, China, France, Germany, UK, Russian Federation, USA, Mexico, Canada, Colombia, Brazil, Argentina, and Australia (see Table A3, appendix). The average value of the period 95-99 was taken from Hoekstra and Hung and compared with the values for 1999 obtained by Colin (with the assumption that water productivity increases by 1% per year).

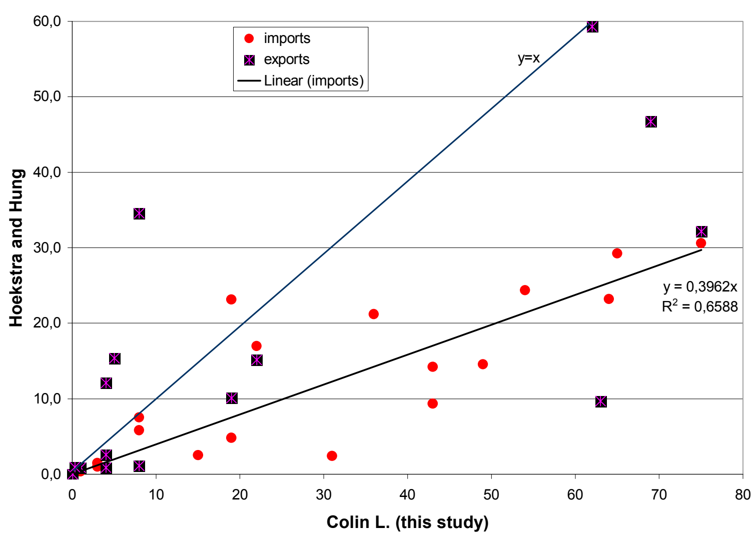

Figure 2. Comparison of imports and exports of virtual water by various countries from Colin (this study) and Hoekstra and Hung (2002).

As shown in the figure and as expected, a rather good correlation is obtained for imports and the values obtained in this study are significantly higher than those of Hoekstra and Hung. The average ratio is only 0.4 which is probably an indication that transformed and processed products represent a great part of the traded products. The latter has been confirmed by further simulations reported in § 4.

For exports, as expected, the correlation is not good.

Oki et al (2002) have also computed values of virtual water trade at global scale. They also used reference virtual water values split into two categories, namely one for exporting countries supposed to be low and one for importing countries supposed to be high. They provide figures at global scale of 1 251 km^3/year for imports and of 866 km^3/year for exports. This again shows that the order of magnitude of virtual water trade is around 1 000 km^3/year.

Douglas (personal comm.) has computed water embedded in food products and traded virtual water for USA. As shown in the table below, the figures obtained from their computation compare very well with our results. But the references utilized in our study were mostly from USA!

Table 5. Water consumption in food products and virtual water exchanges for United States

Results in km^3/yr	Colin L (this study)	Douglas[(1)]
Total water consumption	502[(2)]	638[(2)]
Virtual water exports	234	229
Virtual water imports	65	40

[(1)]personal communication; [(2)] the figure given by Douglas includes grass production contrary to that by Colin.

4. ANALYSIS OF THE GLOBAL WATER FOR FOOD BUDGET

A second attempt to estimate water for food at global scale has been made considering the virtual values of all food products consumed at global level.

4.1. Principles

Food quantities required to sustain global food consumption has been estimated from FAO Balance sheets as follows:

- total production of each item from which we subtract stock changes, feed and others uses and multiply the results with values of virtual water as listed in tables A1 and A2 in appendix.
- virtual water value of sea product and fish are included with an equivalence to animal product (5 m3/kg).
- animals are considered as if they were all grown on feed lots (one way to account for grass and other sources of feed).

The resulting estimation of global water budget for food is expected to be much greater than the previous one which does not account for intermediate consumptions for animals and for sea food.

4.2. Global virtual water budget

Using references of specific water requirements for 1990 (see appendix), the virtual water budget for food amounts to 5 750 km3 for the year 2000. Considering an increase of water productivity of 1% per year (a very conservative assumption), the adjusting factor between 1990 and 2000 would be 0.904 and the estimated virtual water budget for 2000 establishes to **5 200 km3**.

4.3. Partition of virtual water per product

Out of the global budget, meat and animal products represent about 45 % of the budget as shown in figure 3., whereas cereals account for 24%, fish and sea food account for 8% and oil for 8%.

4.4. The importance of cereals for energy and protein

Cereals account for only 24 % of the global virtual water budget but contribute to more than half of the total food energy produced on earth as shown on fig.4, and to almost- half of the protein budget (Fig.5).

Wine and beer contributions to the energetic balance are important in some countries, of Europe in particular. However at global level, alcoholic beverages have a low contribution (1.6%) (Figure 4), to the trade of virtual water.

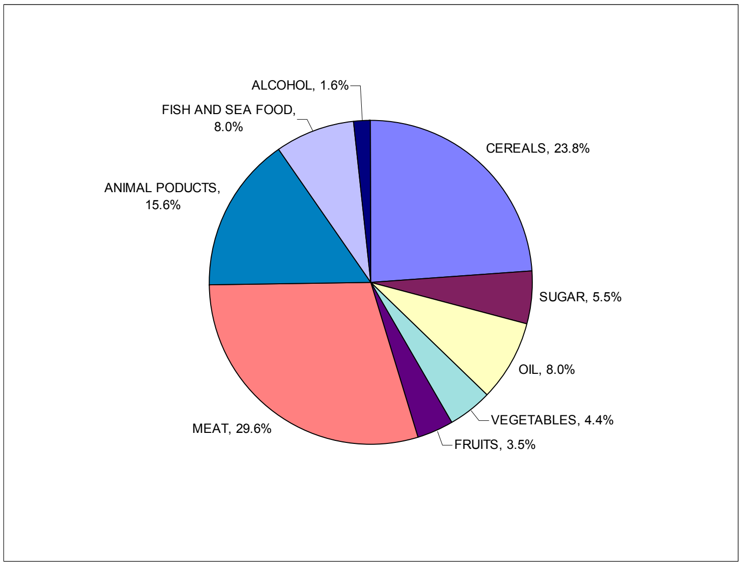

Figure 3. Distribution of global water embedded in food products in 2000 (5 200 Km3).

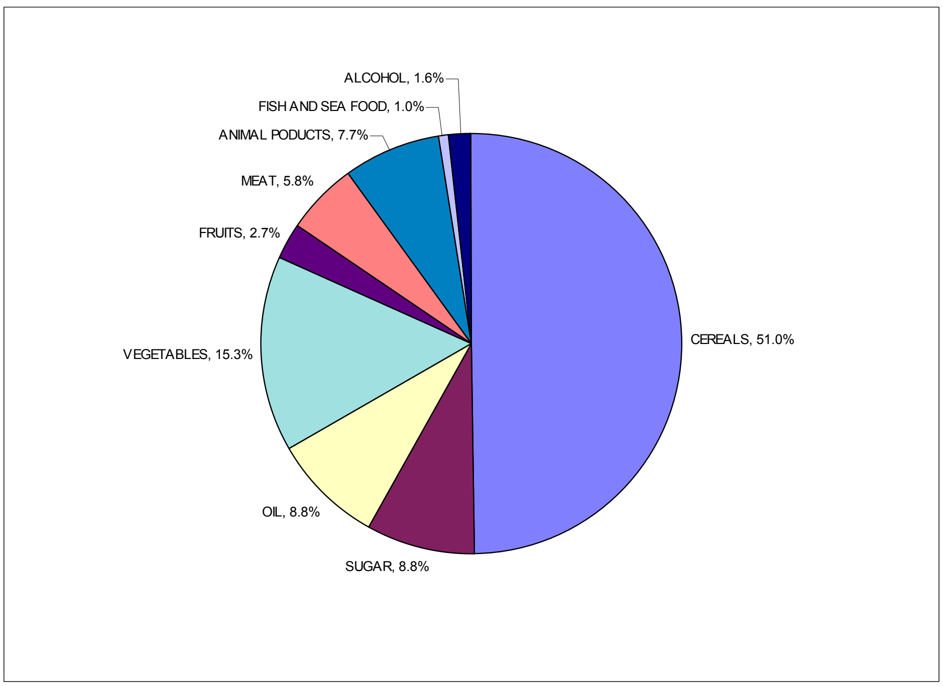

Figure 4. Partition of the global energy budget per food product

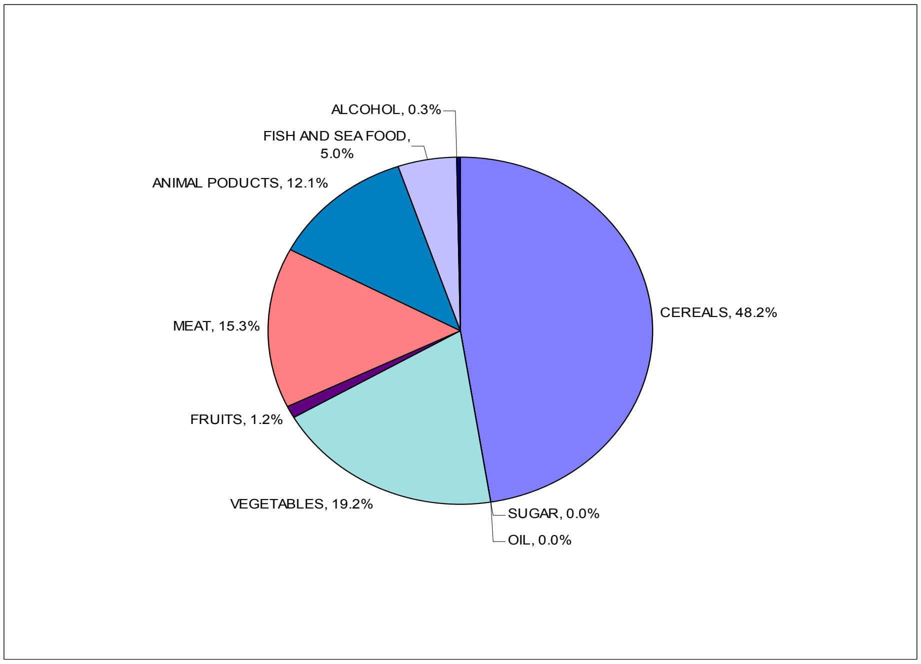

Figure 5 Partition of the global protein budget per food product

5. ANALYSIS OF THE GLOBAL VIRTUAL WATER TRADE

5.1 Virtual water trade: one fourth of the global budget

The virtual water food trade amounts to 1 485 km3 for the year 2000 with references of virtual water values taken for 1990 (see appendix). Assuming an increases in water productivity of 1% per year, the adjusted virtual water trade for 2000 is estimated at about **1 340 km3**. The difference with the results mentioned on table 2 for virtual water trade (1 100km3) is due to the contribution of sea food and fish products.

This figure underlines again the importance of virtual water at global level. **Virtual water trade** in 2000 accounts for **one fourth of the global virtual water budget**, precisely 26%. This importance is likely to dramatically increase as projections show that food trade will increase rapidly: doubling for cereals and tripling for meat between 1993 and 2020 (Rosegrant and Ringler, 1999).

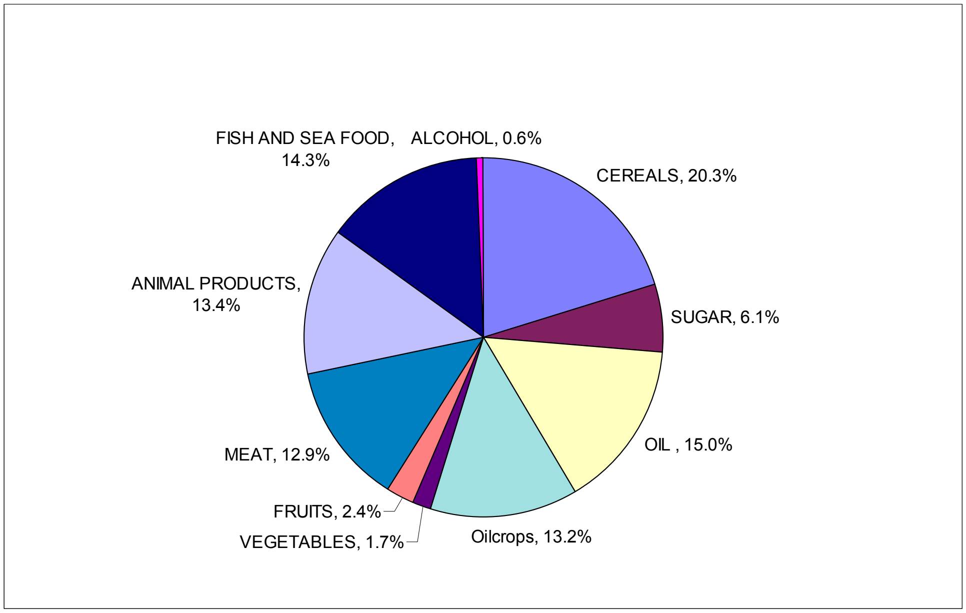

Figure 6. Global virtual water food trade in 2000 (1 340 km3).

It is important to note that part of vegetal products traded are for animal feed (some oil crops and cereals) or for processed products (some oil crops), therefore a fraction of the estimated virtual water trade is counted twice, as primary and transformed products.

5.2. **Partition of virtual water trade per product**

About 60 % of the virtual water trade is from vegetal products, the remaining 40% are shared almost equally by animal products, meat and fish + sea food. Cereals account for 20%, sugar for 6% and oil for 15% and oil crops for 13%.

Quite interesting and unexpected, cereals which have captured most of the attention in food security and virtual water studies, account only for 20 % of the total volume of virtual water exchanged. Of course when it comes to nutritional values, and for arid regions, the importance of cereals is much greater than one fifth. In 2000, cereals contributed to 40 % of the food energy trade as shown in figure 7.

5.3. **Evolution with time of virtual water in food trade**

The food trade has largely increased during the last decades. Figure 8 displays the historical evolution per main type of product. Vegetal products and sea products increase while animal products are more fluctuating. A decrease of animal products trade early 90s followed a sharp increase during the 80s. The political and economical changes and the meat crisis can certainly explain the decrease in early 90s of the virtual water trade. Since 1995, we have retrieved the previous growth trend.

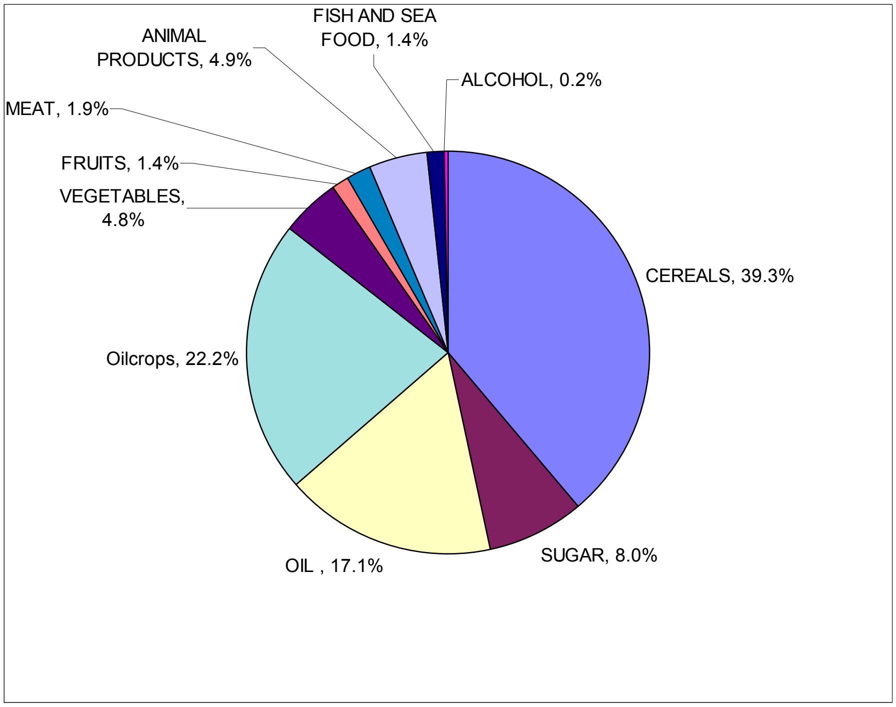

Figure 7. Partition of the global energy food trade per product

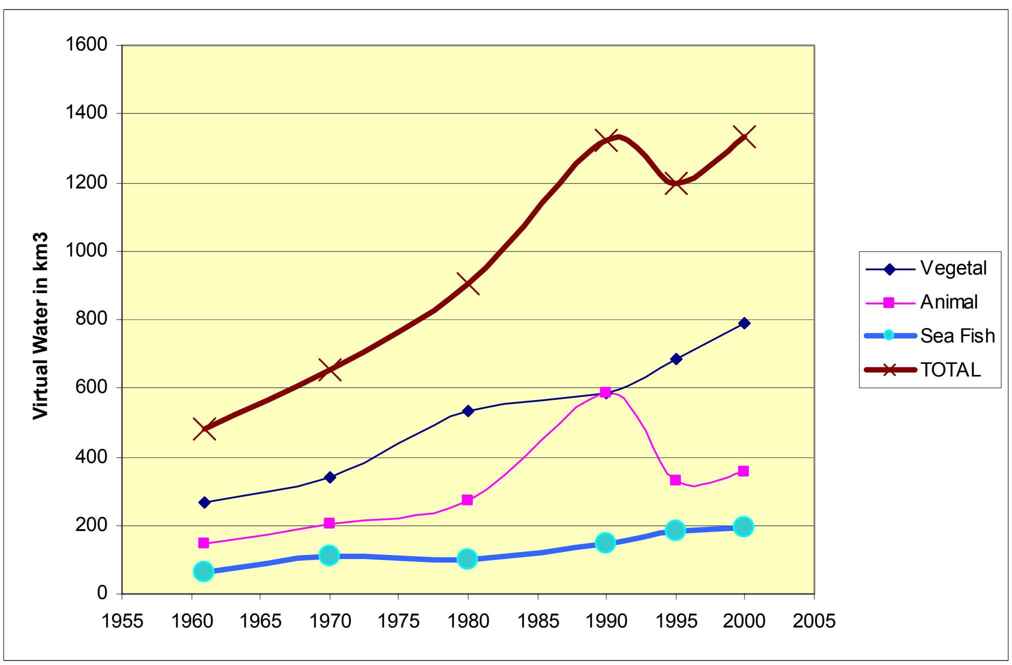

Figure 8. Virtual water in food trade between countries since 1961 considering an increase of water productivity of 1% per year.

5.4. Importance of trade per product

Some product are relatively more traded than others. In fig.9. we plotted the ratio of quantity traded to quantity produced. We can distinguish three categories of products:

- The champions are oil, sea and fish products: about 45 % of the production is traded.
- The middle ones, from 17 to 28 %: cereals, sugar, oil crops, fruits and animal products
- The lower ones, at about 10 %: vegetables, meat and alcoholic beverages.

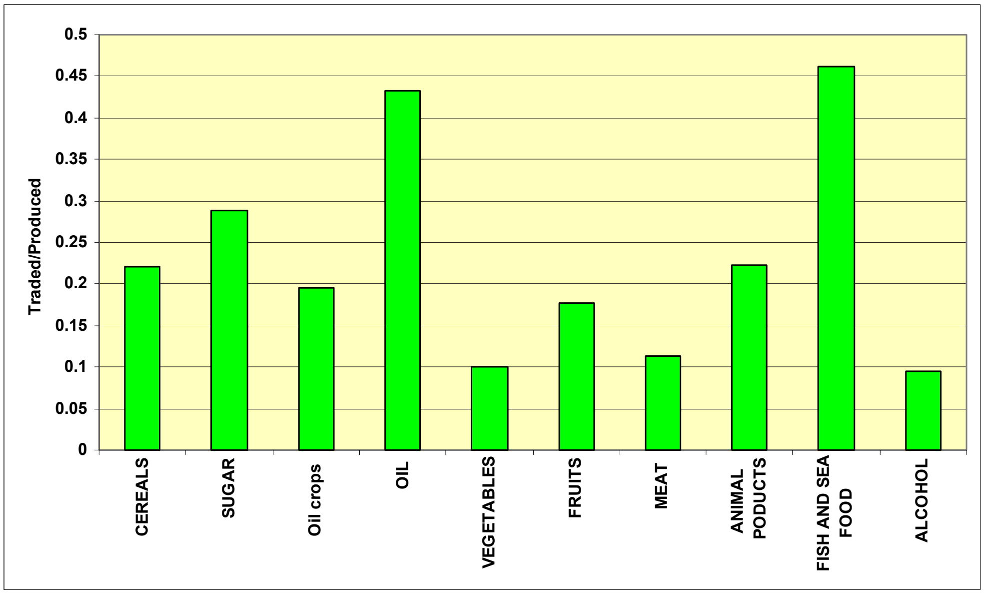

Figure 9. Trade rate per product in 2000.

CONCLUSIONS

The purpose of this paper was twofold: addressing methodological issues and providing preliminary results on global virtual trade. By doing so, our goal is to come up in the future with reliable and accurate methodologies for assessing virtual water. The practical objectives of this study is to map the virtual water budget at global level, in order to organize the next investigations phases with a pertinent framework. Preliminary results on virtual water budget at global level, and on virtual water trade give strong indications on where we should be focussing in the future to improve the accuracy of the assessment. For instance, alcoholic beverages are not enough important to be investigated in detail.

Regarding methodology, there are at least three important aspects that need to be properly addressed:

- Processes and products
- Mapping the fluxes
- Specifying the scope of the studies.

One of the main conclusions at this stage is that virtual water accounts in 2000 for one fourth of the global water budget for food, and it is likely that this ratio will increase in the future. This should be a strong motivation for launching more detailed studies on virtual water.

As expected cereal is the highest contributor to virtual water trade, but unexpectedly its share (20%) is not as high as would be expected from the attention given to virtual water related to cereals trade. Oil and oil crops trade is contributing to a high 28 % of the total. Meat and animal product contribute altogether to 26 %. Fish and sea food virtual water trade contribute to a significant 14 % of the total.

It remains of course important to disaggregate these values in order to have a better understanding of the virtual water streams per product and per regions. It is also important for future works to map the virtual water fluxes considering separately green and blue water.

Virtual water studies are still at a pioneer stage and this is the reason why it is important to compare studies made independently. Despite some variation in the results due to differences in the methods and the references considered, we found that the various assessments of virtual water made so far have provided quite similar values.

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APPENDIX

Table A1. Specific Water Demands or primary vegetal products (Values estimated for 1990)

Products	Specific Water Demand (m3/T)	Country, Reference
Wheat, millet, rye	1159	California, Barthelemy et al
Barley	1910	California, Barthelemy et al
Oats	2374	California, Barthelemy et al
Sorghum	542	Egypt, Barthelemy et al
Rice	1408	California, Barthelemy et al
Maize	710	California, Barthelemy et al
Cereals, others	1159	California, Barthelemy et al
Potatoes	105	California, Barthelemy et al
Sugar beet	193	California, Barthelemy et al
Sugar Cane	318	California, Barthelemy et al
Pulses	1754	Egypt, Barthelemy et al, TS and FAO databases
Tree nuts	4936	Tunisia, Barthelemy et al
Groundnuts	2547	California, Barthelemy et al
Rape and Mustard seed	1521	Germany, BRL data base
Soybeans	2752	Egypt, Barthelemy et al
Olives	2500	Tunisia, Barthelemy et al
Sunflower	3283	Egypt, Barthelemy et al, TS database
Tomatoes	130	California, Barthelemy et al
Onions	168	California, Barthelemy et al
Vegetable, others	195	California, Barthelemy et al
Grapefruit	286	California, Barthelemy et al
Lemons, limes	344	California, Barthelemy et al
Oranges and other citrus	378	California, Barthelemy et al
Bananas	499	California, Barthelemy et al
Apples	387	California, Barthelemy et al
Pineapples	418	California, Barthelemy et al
Dates	1660	California, Barthelemy et al
Grapes	455	California, Barthelemy et al
Fruit, others	455	California, Barthelemy et al

Table A2. Specific Water Demands or transformed or processed products (Values estimated for 1990)

Products	Specific Water Demand (m3/T)	Country, Reference
Cottonseed	1145	California, TS and FAO databases
Coconut oil	5500	Substitution(1)
Palm oil	5500	Malaysia, Indonesia, TS Database
Palmkernel oil	5500	Substitution(1)
Sesame seed oil	5500	Substitution(1)
Groundnut oil	8713	California, Barthelemy et al
Sunflower seed oil	7550	California, Barthelemy et al
Rape and Mustard oil	3500	Germany, BRL data base
Soybean oil	5405	Egypt, Barthelemy et al, TS and FAO databases
Cottonseed oil	5500	California, TS and FAO databases, substitution(1)
Olive oil	11350	Tunisia, Barthelemy et al
Bovine, mutton, goat meat	13500	California, Barthelemy et al
Pig meat	4600(2)	California, Barthelemy et al
Poultry meat	4100	California, Barthelemy et al
Other meat	13500	California, Barthelemy et al
Eggs	2700	California, Barthelemy et al
Milk	790	California, Barthelemy et al
Butter + Fat	18000	California, Barthelemy et al
Sugar	1929	California, Barthelemy et al, TS database
Sweeteners	2731	California, Barthelemy et al, TS database

(1) no values found, substitution with palm oil value which is the most traded oil utilised
(2) value to be debated in countries where pork is fed mainly with waste products

Table A3. Water consumed for crop production and virtual water traded from various countries for year 1999, assuming an annual increase of 1% in water productivity. Values in km^3/year.

Country	Water for crop production	Virtual Water imported	Virtual water exported	Net virtual water balance	Virtual water balance/ water for food (%)
Argentina	114	3	69	-66	-58
Australia	64	3	85	-82	-128
Brazil	251	19	75	-57	23
Canada	93	19	62	-43	-46
China	624	75	19	56	9
Colombia	23	8	4	4	17
Egypt	32	22	1	21	65
Ethiopia	11	1	0.04	1	9
France	103	43	91	-48	-47
Germany	75	64	63	1	1
India	423	31	8	23	5
Indonesia	422	36	8	27	6
Mexico	47	54	5	49	104
Nigeria	47	8	0.3	7	15
Pakistan	56	15	4	11	20
Russian Federation	93	49	4	45	48
UK	35	43	22	21	60
USA	502	65	234	-169	-34