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ACCOUNTING FOR WATER SCARCITY AND POLLUTION IN THE RULES OF INTERNATIONAL TRADE

AMSTERDAM, 25-26 NOVEMBER 2010

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Foreword

In the recent years, water scarcity, water pollution and water management have been among the important focus fields in the research agenda of the European Science Foundation (ESF). The interdisciplinary nature of these topics necessitates assembling more discussion platforms. Therefore, in the course of 2010, the European Science Foundation (ESF) invited experts from the University of Twente, Enschede, the Netherlands to organise an international workshop on the relation between freshwater management and international trade. The strategic workshop on "**Accounting for water scarcity and pollution in the rules of international trade**" (see, www.esf.org/water-trade) was held on 25th-26th November 2010 at the NEMO Science Centre in Amsterdam, the Netherlands as an initial attempt to cover key issues and current challenges in relation to the linkages between water management and international trade. The workshop was organised by the ESF Standing Committees for Life, Earth and Environmental Sciences (LESC) and for Social Sciences (SCSS) of the European Science Foundation (ESF) and the University of Twente in collaboration with the United Nations Environment Programme (UNEP). The workshop was sponsored by ESF and UNEP, and supported by the Water Footprint Network and the Global Water Partnership.

The aim of the Strategic Workshop was to create an interdisciplinary forum bringing together water experts, international trade scientists and policy makers to share knowledge and expertise and to discuss issues of common concern, such as the inter-linkages between water conservation and international trade, and to develop a common understanding and common research questions. The workshop brought together 31 leading water experts, trade scientists, policy advisers and policy makers to share and integrate knowledge and expertise between the hitherto unconnected water management and international trade communities. The workshop made it possible for the participants to initiate new lines of research and synergistic contacts throughout Europe and beyond, and to further understand how to incorporate virtual-water trade knowledge into international trade regulations, in order to increase water-use efficiency and to achieve a sustainable water management at a global level.

The current proceedings contain the full papers based on some of the presentations that were held during the two-day Strategic Workshop. On behalf of LESC and SCSS, we would like to sincerely thank all the participants of the workshop, authors of the papers and the organisers.

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Preface

Traditionally, water resources management has been dealt with from the local, river basin or national perspective. Even if it is increasingly recognised that water governance has a global dimension, the linkages between international trade and freshwater scarcity and demand are rarely analysed. An obvious effect of international trade in water-intensive commodities is that it generates water savings in the countries that import those commodities. This effect has been discussed since the mid-1990s. The other side of international trade in water-intensive commodities is that it consumes water in the exporting countries, which can no longer be used for other (domestic) purposes. Besides, the social and environmental costs that are often associated with water use remain in the exporting countries; they are not included in the price paid for the water-intensive products by the consumers in the importing countries. International trade can help saving water globally when a water-intensive commodity is traded from an area where it is produced with high water productivity (low water input per unit of output) to an area with lower water productivity (high water input per unit of output). On the other hand, there can be a global increase in total water consumption if a water-intensive commodity is traded from an area with low to an area with high water productivity if the product could have been produced in the importing country instead.

Even though nowadays water is seldom the dominant factor determining trade in water-intensive commodities, it can become increasingly important in the context of a growing global demand for water-intensive products and increasing water scarcity in various regions of the world. Virtual water flows are mainly subordinated to world trade rules. World Trade Organization (WTO) policies affect national agricultural policies, and these in turn affect irrigation water use. It is therefore worthwhile further exploring the possibility of incorporating water sustainability considerations into international trade regulations.

International trade presently involves a significant part of products for which production is water-intensive. In order to protect and preserve freshwater resources and reduce negative impacts on the environment and socio-economic systems, the United Nations and the WTO will have to address the link between international trade and sustainable water use. Within Europe, the link between international trade and sustainable water use will need to be addressed within the framework of the European Single Market, not only in the EU Water Framework Directive. Regarding the WTO, trade in virtual water can be discussed in relation to several aspects of the WTO work programme that is currently being negotiated.

This volume is a collection of papers that were discussed at and revised and peer-reviewed after the ESF Strategic Workshop on “Accounting for water scarcity and pollution in the rules of international trade” that was held 25-26 November 2010 in Amsterdam. The papers are highly diverse from a number of perspectives. The authors come from different disciplines, use different terminologies, apply different analytical frameworks and work from different assumptions. In the first paper, **Hoekstra** discusses international trade from a water management and environmental perspective. In the second paper, **Allan** takes a political economy perspective, which fundamentally differs from the free-market perspective taken by **Rogers and Ramirez-Vallejo** in the third paper. In the fourth paper, **Niemeyer and Garrido** write from an agricultural economist point of view and address the relation between food trade, food security and sustainable water use. In the fifth paper, **Granit and Lindström** address the linkage between today's freshwater and energy challenges. In the sixth paper, **Chahed, Besbes and Hamdane** take a water engineering and management perspective on the question of the 'optimal' virtual water trade balance for a water-scarce country, taking Tunisia as an example. Finally, **Le Vernoy and Messerlin** discuss the water-trade nexus from their background as economists specialised in international trade and trade policy.

As it stands now, it is clear that we are only at the very beginning of a scientific undertaking to understand better the relation between freshwater management and international trade. The inherent interdisciplinary character of this relation requires the involvement of many disciplines. In the field of water management a multidisciplinary approach is not unusual, but the link between water management and international trade has mainly remained out of scope for water managers. Since freshwater is a scarce resource and thus – by definition – an economic resource, taking an economic perspective to understand water use patterns in an international context seems logic, but is far too limited. Freshwater is a public resource, its natural flow is fundamental to the sustenance of ecosystems and its allocation to alternative uses is a highly sensitive socio-political issue. In understanding the relation between international trade and patterns of water scarcity and water quality, the environmental, social and political dimensions are as important as the economic dimension. An important scientific challenge is therefore to develop interdisciplinary conceptual and analytical frameworks that enable a more thorough and integrated understanding.

We would like to thank the European Science Foundation and Shaoyi Li and Guido Sonnemann from the United Nations Environment Programme for their support.

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1. The relation between international trade and freshwater scarcity[1]

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Abstract

It is becoming increasingly important to put freshwater issues in a global context. In many places, freshwater is being consumed and polluted for making export goods. Freshwater use is generally priced far below its economic and environmental cost, and the prices of traded commodities do not reflect the costs of the water that was consumed or polluted during production. Global production and trade patterns are thus unlikely to be influenced by regional differences in water scarcity. At the same time, however, it has been proven that freshwater constraints in water-short countries do influence trade, by forcing these countries to rely on the import of water-intensive commodities. This paper addresses four questions: What is the effect of international trade on domestic water resources? What is the effect of water availability on international trade? Can international trade increase global water-use efficiency? And finally, what type of international trade rules would promote a wiser use of water worldwide? The paper identifies three mechanisms that could help ensure that trade and sustainable water use go hand in hand: product transparency, e.g. through a water label, an International Water Pricing Protocol and an International Water-Footprint Permit System. International agreements on the liberalisation of trade in agricultural products – as being negotiated in the WTO's ongoing Doha Development Round – should include provisions that promote sustainable water use in agriculture. As yet, it is unclear how such provisions could look like, since the WTO explicitly refrains from making environmental agreements. An imbalance in global trade regulations will be created as soon as free trade agreements are effective while sustainable-product and sustainable-water-use agreements to constrain international trade are not yet existent. This is a serious risk, since no international agreements on sustainable water use or sustainable products do exist or are being prepared.

Introduction

The recent past has shown a growing interest from both trade and water experts in the relation between international trade and freshwater scarcity. Until recently, it has not been very common for water sector specialists to look at the relation between water use in a region and import into or export from this region. Traditionally, in their view, water demand in an area is simply a function of the amount and needs of the water users in that area. At the same time, economists do generally not consider much the implications of international trade for the water sector. The reason is that water inputs usually hardly contribute to the overall price of traded commodities. This seems to justify the conclusion that water cannot be a significant factor influencing production and trade patterns. The fact that water inputs are often heavily subsidised by national governments is hereby ignored. Trade specialists also tend to overlook that external effects of water use can be very significant, but are never included in the price of water, and that no country charges a scarcity rent for water inputs even though water is sometimes very scarce. When merely looking at the prices of traded commodities, one will indeed get the impression that water scarcity cannot be a driving force of or limiting factor to international trade.

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[1] Adapted from Hoekstra, A.Y. (2010) The relation between international trade and freshwater scarcity, Working Paper ERSD-2010-05, January 2010, World Trade Organization, Geneva, Switzerland.

Water is usually not regarded as a global resource. Whereas in most countries the energy sector has an obvious international component, this is different for the water sector. The international characteristics of water are recognised in the case of trans-boundary rivers, but the relation between international trade and water management is generally not something that water sector officials think much about. It is probably because water itself is not traded internationally, due to its 'bulky' properties. Besides, there is no private ownership of water so that it even cannot be traded as in a market (Savenije, 2002). Water sector specialists forget, however, that water is traded in virtual form, i.e. in the form of agricultural and industrial commodities (Hoekstra and Hung, 2005; Chapagain and Hoekstra, 2008). Although invisible, import of 'virtual water' can be an effective means for water-scarce countries to preserve their domestic water resources (Allan, 2001a).

One of the principles widely accepted in water resources management is the subsidiarity principle, according to which water issues should be settled at the lowest community level possible (GWP, 2000). In cases where upstream water uses affect downstream uses, it has been recognised that it is necessary to take the perspective of a river basin as a whole, considering water as a river-basin resource. Regarding water as a global resource is very uncommon. The Global Water Partnership (GWP, 2000) writes: 'In order to achieve efficient, equitable and sustainable water management […], a major institutional change will be needed. Both top-down and bottom-up participation of all stakeholders will have to be promoted – from the level of the nation down to the level of a village or a municipality or from the level of a catchment or watershed up to the level of a river basin. The principle of subsidiarity, which drives down action to the lowest appropriate level, will need to be observed.' There is no word about a global dimension of the water governance.

Considering water management from a local, national or river-basin perspective is, however, often insufficient. Many water problems are closely linked to international trade (Hoekstra and Chapagain, 2008). For instance, subsidised water in Uzbekistan is overused to produce cotton for export; Thailand experiences water problems due to irrigation of rice for export; Kenya depletes its water resources around Lake Naivasha to produce flowers for export to the UK and the Netherlands; Chinese rivers get heavily polluted through waste flows from factories that produce cheap commodities for the western market. Not only water problems, but also water solutions have an international trade component. For instance, Jordan and various other countries in the Middle East meet their demand for food and save their scarcely available water resources through food imports from overseas (Chapagain et al., 2006a); Mediterranean countries will expectedly experience increased water scarcity due to climate change, forcing them into the direction of increased import of water-intensive products. Apparently, there are more connections between seemingly local or national water issues and international trade than recognised at first sight.

This paper reviews current knowledge with respect to four questions:

- what is the effect of international trade on domestic water resources?
- what is the effect of water availability on international trade?
- can international trade increase global water-use efficiency?
- what type of international trade rules would promote a more wise use of water worldwide?

But before addressing these questions, we will first consider the characteristics of freshwater that make it different from other resources. The paper will be concluded with a discussion of risks and opportunities associated with the intensification of international trade in water-intensive commodities.

What is special about freshwater?

Freshwater is a scarce resource

Freshwater is a scarce resource because its annual availability is limited and its demand is growing. It is impossible to 'produce' water; one can only deviate or temporarily store natural flows in order to have access to it at another location or point in time. There are, however, limitations to this, since water transfer and storage are due to different sorts of constraints. First of all, because water is bulky, transferring or storing it is quite costly, and requires large infrastructure. Second, taking water out of its natural flow and returning it elsewhere or at another point in time will affect ecosystems that are adapted to the natural flow. Significant changes to natural flows generally have undesired consequences for both downstream ecosystems and downstream users.

Freshwater is a renewable but finite resource

Water is a renewable resource, but that does not mean that its availability is unlimited. Over a certain period, precipitation is always limited to a certain amount. The same holds for the amount of water that recharges groundwater reserves or flows through a river. Rainwater can be used in agricultural production and water in rivers and aquifers can be used for irrigation or industrial or domestic purposes. But, over a certain period one cannot use more water than is available. One cannot take more from a river than what flows in it and in the long term one cannot take more water from lakes and groundwater reservoirs than the rate by which they are recharged.

Freshwater can be 'overexploited'

There are many spots in the world where serious water depletion or pollution events or practices take place: rivers running dry, dropping lake and groundwater levels, and endangered species because of contaminated water. 'Available' does not mean that water can always be fully consumed without undesired consequences.

Freshwater is a public resource

Everywhere in the world, freshwater is a public resource. People can own the land but not the freshwater that stays or flows on or underneath it. Freshwater is neither privately owned nor traded. When the term 'water privatisation' is used, one generally refers to the privatisation of water supply, which means that the services of collecting, purifying and distributing and/or the services of wastewater collection and treatment are privatised. The term does not mean that the water itself is privatised.

Freshwater availability strongly varies in time

Many regions of the world face both water scarcity and water flooding. Scarcity happens in the dry period, flooding in the wet period of the year. The competition for and economic value of the water resources fluctuate accordingly throughout the year. This is a very specific property of freshwater, a property that one cannot find for other resources or commodities.

Freshwater availability strongly varies in space.

The amount of freshwater varies strongly over space as well. In this respect, freshwater is just like oil. Some countries have a lot of it, while others have not. Freshwater is thus a geopolitical resource in a similar way as oil (Hoekstra and Chapagain, 2008). Abundance of oil or freshwater gives a comparative economic advantage in goods that require for their production a lot of energy or freshwater respectively, but it also constitutes a form of political power (Allan, 2001b).

Freshwater productivity strongly varies

Water productivity – defined as the output per unit of water volume consumed – varies strongly from place to place. This is not just a matter of available technology or available human, social or institutional capital. Water productivity is also related to climate and other environmental factors. From a climate and soil perspective, the water of the Nile can be made more productive for making crops in the highlands of Ethiopia than for making the same crops downstream in the desert of Egypt. In this particular case, however, the actual water productivity in Egypt reaches close to its potential, while in Ethiopia, the actual productivity is far below its potential, so that Egypt's actual water productivity is still higher. The fact that different countries have different water productivities creates a comparative advantage for those countries that have relatively high water productivity in producing particular water-intensive crops. This is, however, a theoretical rather than practical advantage, because real economic costs of water inputs are never fully charged to the water users, and water will not be a decisive factor in production, unless in cases where water shortages will simply hamper production.

Freshwater is generally priced far below its economic value

Most governments subsidise water supply on a huge scale by investing in infrastructure like dams, canals, water purification, distribution systems, desalination plants and wastewater treatment. These costs are often not charged directly to the water users. As a result, there is insufficient economic incentive for water users to save water. Besides, due to the public character of water, water scarcity is generally not translated into an additional component in the price of goods (and services) that are produced with the water, as happens naturally in the case of private goods. Finally, water users generally do not pay for the negative impacts that they cause on downstream people or ecosystems. As a result, water inputs do not form a substantial component of the total price of even the most water-intensive products. Consequently, the production of and trade in goods – even though various sorts of goods require a lot of scarce water inputs – is not or hardly governed by water scarcity. The only constraint on production is absolute water scarcity: when the river is dry there will be no further water use downstream. As Yang et al. (2003) have shown, absolute water scarcity indeed hampers production and necessitates imports of water-intensive goods like cereals in the most water-scarce regions of the world.

Water is not being traded

When people speak about 'water markets' or 'water trading', they refer to the trade of water use rights, also briefly called water rights or water entitlements. Only a few countries or states – like Chile and California – have such 'water markets' but most countries have not. In water markets, the water is not really traded as in the case of other tangible commodities. It is the water use rights that are traded. In the field, this means that one farmer can irrigate his field with a certain amount of water, and not another farmer, when the first one holds the water use right. Or, one industry can withdraw some volume of water and not another industry that is based along the same river or above the same aquifer. The only form of water trade occurs in the form of trade in bottled water (Gleick, 2004) and other beverages. This sort of trade, however, concerns relatively small volumes. People drink no more than a few litres of liquids per day, while the total water use per capita – for producing all goods and services consumed – amounts to at least a few thousands of litres per day.

International real and virtual water transfers

International trade in bottled drinking water and other beverages does exist but is very small from a volume perspective. From a hydrological point of view, it is irrelevant. Bulky international water trade hardly exists. Freshwater crosses international borders in the case of trans-boundary rivers like the Nile, Mekong or Danube, but otherwise there are only rare instances of international water transfers. A recent example was in spring 2008 when the Spanish city of Barcelona had to ship in freshwater from France. Various islands, including Aruba, Nauru, Tonga and the Canary Islands have at times received freshwater by tanker from elsewhere (Gleick et al., 2002). Much larger-scale international water transfers have been proposed throughout the world, like the idea of transferring water from Congo to Chad or from Northern Russia and Siberia to Central Asia, or from Antarctica to the Persian Gulf. Whether these mega-engineering plans will be realised is doubtful, due to the enormous costs and social and environmental consequences. At least until today, one can say that international water trade or transfers are very small on a global scale. What happens, however, on a very substantial scale, is transfer of water in embedded form, i.e. in the form of goods. It is not that the amounts of water actually contained in goods are so large, but the water volumes virtually embedded in goods can be huge. By consuming water in one country to produce a product that is traded to another country, the water is virtually transferred to the importing country. In this context we speak about 'virtual water trade', although 'transfer' would be a better term, because the goods are traded, not the water.

The effect of international trade on domestic water resources

An obvious effect of international trade in water-intensive commodities is that it generates water savings in the countries that import those commodities. This effect has been discussed since the mid-1990s (Allan, 2001b; Hoekstra, 2003). The national water saving associated with import can be estimated by multiplying the imported product volume by the volume of water that would have been required to produce the product domestically. The other side of international trade in water-intensive commodities is that takes water in the exporting countries that can no longer be used for other (domestic) purposes. Besides, the social and environmental costs that are often associated with water use remain in the exporting countries; they are not included in the price paid for the products by the consumers in the importing countries.

Import of water-intensive commodities reduces national water demand

In many countries, international trade in agricultural products effectively reduces domestic water demand (Table 1.1). These countries import commodities that are relatively water-intensive while they export commodities that are less water-intensive. During the period 1997-2001, Japan, the largest (net) importer of water-intensive goods in the world, annually saved 94 billion m^3 from its domestic water resources. This volume of water would have been required, in addition to its current water use, if Japan had produced all imported products domestically. In a similar way, Mexico annually saved 65 billion m^3, Italy 59 billion m^3, China 56 billion m^3, and Algeria 45 billion m^3 (Chapagain et al., 2006a).

Table 1.1. Examples of nations with net water saving as a result of international trade in agricultural products. Period 1997-2001.

Country	Total use of domestic water resources in the agricultural sector[1] (10^9 m^3/yr)	Water saving as a result of import of agricultural products[2] (10^9 m^3/yr)	Water loss as a result of export of agricultural products[2] (10^9 m^3/yr)	Net water saving due to trade in agricultural products[2] (10^9 m^3/yr)	Ratio of net water saving to use of domestic water
China	733	79	23	56	8%
Mexico	94	83	18	65	69%
Morocco	37	29	1.6	27	73%
Italy	60	87	28	59	98%
Algeria	23	46	0.5	45	196%
Japan	21	96	1.9	94	448%

[1] Source: Hoekstra and Chapagain (2008)

[2] Source: Chapagain *et al*. (2006a). Agricultural products include both crop and livestock products.

One of the water-scarce countries that most heavily depend on imports of water-intensive commodities is Jordan. It imports five to seven billion m^3 of water in virtual form per year, which is in sharp contrast with the 1 billion m^3 of water withdrawn annually from domestic water sources (Haddadin, 2003; Hoekstra and Chapagain, 2007, 2008). People in Jordan thus survive owing to the fact that their 'water footprint' has largely been externalised to other parts of the world, for example the USA. Wise trade largely covers up Jordan's water shortage: export of goods and services that require little water and import of products that need a lot of water. The positive side of Jordan's trade balance is that it preserves the scarce domestic water resources; the downside is that the people are heavily water dependent on other countries.

For countries that depend on the import of water-intensive products, it is important to know whether the water thus saved has higher marginal benefits than the additional cost involved in importing these products. Let us consider the example of Egypt, a country with a very low rainfall – the mean rainfall is only 18 mm/yr – and with most of its agriculture being irrigated. The import of wheat in Egypt implies a saving of their domestic water resources of 3.6 billion m^3/yr, which is about 7% of the total volume of water Egypt is entitled to according to the 1959 agreement on the use of the Nile River. The national water saving is made with the investment of foreign exchange of 593 million US$/yr (ITC, 2004), so the cost of the virtual water is 0.16 US$/$m^3$ at most. In fact, the cost will be much lower, because the costs of the imported wheat cover not only the cost of water, but also the costs of other input factors such as land, fertiliser, and labour. In Egypt, fertile land is also a major scarce resource. The import of wheat not only releases the pressure on the disputed Nile water, but also reduces pressure to increase the area of land under agriculture. Greenaway et al. (1994) and Wichelns (2001) have shown that, in the international context, Egypt has a comparative disadvantage in the production of wheat, and that the import of wheat into Egypt implies not only a physical water saving, but also an economic saving.

Export of water-intensive commodities raises national water demand

Water is not merely a local resource to meet local demands for water-based products. In the period 1997-2001, sixteen per cent of the water use in the world was not for producing products for domestic consumption but for producing goods for export (Hoekstra and Chapagain, 2007, 2008). The nations with the largest net annual water use for producing export goods were the USA (92 billion m^3), Australia (57 billion m^3), Argentina (47 billion m^3), Canada (43 billion m^3), Brazil (36 billion m^3), and Thailand (26 billion m^3). The main goods behind the national water use for export from the USA were oil-bearing crops and cereal crops. These goods are grown partly rain-fed and partly irrigated. In Australia and Canada, the water use for export was mainly related to the production of cereals and livestock products. In Argentina and Brazil, water use for export was primarily for producing oil-bearing crops. The national water use for export in Thailand was mainly the result of export of rice. Much of the rice cultivation in Thailand is done during the rainy season, but irrigation is widespread, to achieve two harvests per year. In the period 1997-2001, Thailand used 27.8 billion m^3/yr of water (sum of rainwater and irrigation water) to produce rice for export, mostly grown in the central and northern regions (Maclean et al., 2002). The monetary equivalent of the rice export was 1,556 million US$/yr (ITC, 2004). Hence, Thailand generated a foreign exchange of 0.06 US$ per m^3 of water used.

With currently sixteen per cent of the water used in the world for producing export goods, and assuming that, on average, production for export does not cause significantly more or fewer water-related problems (such as water depletion or pollution) than production for domestic consumption, roughly one sixth of the water problems in the world can be traced back to production for export. Consumers do not see the effects of their consumption behaviour due to the distance between areas of consumption and areas of production. The benefits are at the consumption side, and, since water is generally grossly under-priced, the costs remain at the production side. From a water-resources point of view, it would be wise for the exporting countries in the world to review their water use for export and decide to which extent this is good policy given the fact that the foreign income associated with the exports generally does not cover most of the costs associated with the use of domestic water. The construction of dams and irrigation schemes and even operation and maintenance costs are often covered by the national or state government. Negative effects downstream and the social and environmental costs involved are not included in the price of the export products as well.

The effect of international trade on local water pollution

International trade brings along another phenomenon: natural cycles of nutrients such as nitrogen and phosphorus are disturbed through depletion of the soil in some places, excessive use of fertilisers in others, long-distance transfers of food and animal feed and concentrated disposal of nutrient-rich wastes in densely populated areas of the world (Grote et al., 2005). This has already led and will further lead to depletion of the soils in some areas (Sanchez, 2002; Stocking, 2003) and to eutrophication of water elsewhere (McIsaac et al., 2001; Tilman et al., 2001). The surplus of nutrients in the Netherlands, for instance, is partially related to deforestation, erosion and soil degradation in those areas of the world that export food and feed to the Netherlands, for example in Brazil from where a lot of soybeans are exported as feed for the Dutch pigs and chickens. This implies that the nutrient surplus in the Netherlands is not an issue that can simply be understood as a Dutch issue. Dutch water pollution is part of the global economy.

The disturbance of nutrient cycles is not the only mechanism through which international trade influences the quality of water resources worldwide. Meybeck (2004) shows how other substances are also dispersed into the global environment and change the water quality of the world's rivers. Nriagu and Pacyna (1988) set out the specific impacts of the use of trace metals in the global economy on the world's water resources. The regular publication of new reports on global water pollution shows that this phenomenon in itself is no longer news; what is now gradually being uncovered and therefore relatively new is the fact that pollution is not simply 'global' because pollution is so 'widespread', but that it is interlinked with how the global economy works and is therefore a truly global problem. Water pollution is intertwined with the global economic system to such an extent that it cannot be dealt with independently from that global economy. Indeed, pollution can be tackled by end-of-pipe measures at or near the location of the pollution, but a more cause-oriented approach would be restructuring the (rules for the) global economy, with the aim of the sustainable closure of elemental cycles.

The effect of water availability on international trade

There is an immense body of literature about international trade, but there are only few scholars who address the question of to which extent international trade is influenced by regional differences in water availability or productivity. International trade is rather explained in terms of differences in labour productivities, availability of land, domestic subsidies to agriculture, import taxes, production surpluses and associated export subsidies, etc. It would be hard to find evidence that regional water abundance benefits the export of water-intensive commodities and that regional water scarcity promotes the import of water-intensive commodities.

According to international trade theory that goes back to Ricardo ([1817] 2006), nations can gain from trade if they specialise in the production of goods and services for which they have a comparative advantage, while importing goods and services for which they have a comparative disadvantage. The meaning of this principle for the field of water resources has been elaborated by Wichelns (2004). The economic efficiency of trade in a water-intensive commodity between two countries should be evaluated based on a comparison of the opportunity costs of producing the commodity in each of the trading nations. Export of a water-intensive commodity is attractive if the opportunity cost of producing the commodity is comparatively low. This is the case when there is a relatively high production potential for the water-intensive commodity due to for example relative abundance of water and/or a relatively high water productivity (yield per unit of water input) in the country. Import of a water-intensive commodity (instead of producing it domestically) is attractive if the opportunity cost of producing the commodity is comparatively high, for example because water is relatively scarce and/or water productivity in the country is low.

The most convincing research providing evidence that water availability influences international trade has been carried out by Yang et al. (2003, 2007). As they have quantitatively shown, cereal imports have played a crucial role in compensating water deficits in various water-scarce countries. They demonstrate that below a certain threshold in water availability, an inverse relationship can be identified between a country's cereal import and its renewable water resources per capita. In the early 1980s, the threshold was at about 2000 m^3 per capita per year. At the end of the 1990s, it had declined to about 1500 m^3 per capita per year. Countries with less water than the threshold cannot do without the import of staple foods. The threshold declined over the past couple of decades thanks to the improvement in water productivities and the expansion of irrigated areas.

There is clear evidence that the trade balance of countries with very low water availability (per capita) is partly determined by the fact that those countries have a comparative disadvantage in producing water-intensive products. The available water resources simply fall short in some countries to produce the food to survive. Most international trade in the world, however, has little to do with the intentional trade in water-intensive commodities to countries with low water availability from countries with higher water availability. The driving force behind international trade in water-intensive products can be water scarcity in the importing countries, but more often other factors play a decisive role (Yang et al., 2003; De Fraiture et al., 2004).

International trade in agricultural commodities depends on many more factors than differences in water availability in the trading nations, including differences in availability of land, labour, knowledge, and capital, and differences in economic productivities in various sectors (Wichelns, 2010). The existence of domestic subsidies, export subsidies, or import taxes in the trading nations will also influence the trade pattern. As a consequence, international virtual-water transfers usually cannot – or can only partly – be explained on the basis of differences in water availability and productivity.

In some cases, the relation between water availability and the actual trade pattern is even counter-intuitive. North China for instance has a very low availability of water per capita, unlike South China, but nevertheless, there is a very significant trade in food from North to South China (Ma et al., 2006). Of course, this trade intensifies the water problems in the North. A similar case can be found in India, where water has become relatively scarce in the northern states of Punjab, Uttar Pradesh and Haryana. Nevertheless, these states export significant volumes of food to the eastern states of Bihar, Jharkhand and Orissa, which have much larger water endowments than the northern states (Verma et al., 2009). No simple reason will suffice to explain the counter-intuitive situations with respect to the internal trade within China and India, because various factors will play a role, including historical, political and economic ones. One factor that may play a role as well is that in water-scarce regions the incentives to increase water productivity are greater. As a result, it becomes attractive to produce in those regions, which however enhances their water scarcity. This may be a factor in northern India, where water productivities are indeed much higher than in the eastern states, providing them with a comparative advantage though the water availability in absolute terms is much lower.

Forecasts of how international trade patterns will develop generally ignore water as a possible constraint to production and pay no attention to the role of freshwater in terms of comparative advantage. As a result, some of the scenarios developed predict increased agricultural production in areas where water is already highly scarce or even over-drafted. Liao et al. (2008) illustrate this for the case of China by studying the effect of trade liberalisation that will likely follow China's accession to the World Trade Organization in 2001. They show that existing projections of agricultural production and trade, which ignore water as a production factor, are unrealistic. Including water as a constraint leads to projections where cereal imports into China will be much higher than previously thought, and to less optimistic prospects with respect to increased export of vegetables.

Global water-use efficiency

In the water sector, the term water-use efficiency is most often used to refer to the inverse of local water productivity. The latter is expressed as the amount of goods made per unit of water (in the agricultural sector known as 'crop per drop'). The water-use efficiency is expressed as the volume of water required to make one unit of good. A water user can increase local water-use efficiency by producing the same with less water input. Water users can be encouraged to do so by charging them a water price based on full marginal cost, by promoting or subsidising water-saving technology, or by creating awareness that saving water is good for the environment and themselves.

The local view on water-use efficiency is only one way of looking at water-use efficiency. There are two other levels at which one can consider the efficiency of water use (Hoekstra and Hung, 2005). At the catchment or river basin level, water-use efficiency refers to the efficiency of water allocation to alternative uses. Water-use efficiency at this level can be enhanced by re-allocating water to purposes with higher marginal benefits (Rogers et al., 1998). At the global level, water-use efficiency can be increased when nations use their comparative advantage or disadvantage in producing water-intensive goods to either encourage or discourage the use of domestic water resources for producing export commodities.

Much research effort has been dedicated to studying water-use efficiency at the local and river basin levels. The research on global water-use efficiency is more recent. Only four studies have been carried out so far, all of them focusing on the quantification of physical water savings as a result of global trade, not on the economic savings associated. All four studies indicate that the current pattern of international trade results in a substantial global water saving (Oki and Kanae, 2004; De Fraiture et al., 2004; Chapagain et al., 2006a; Yang et al., 2006).

Volume of water saved as a result of international trade

The most comprehensive study on global water saving in relation to international trade was the one carried out by Chapagain et al. (2006a). According to their study, the global water use for producing agricultural products for export amounted to 1,250 billion m^3/yr (in the period 1997-2001). If the importing countries were to have produced the imported products domestically, they would have required a total of 1,600 billion m^3/yr. This means that the global water saving by trade in agricultural products was 350 billion m^3/yr. So the average water saving accompanying international trade in agricultural products has been (350/1,600=) 22%. The global volume of water used for agricultural production is 6,400 billion m^3/yr. Without trade, supposing that all countries had to produce the products domestically, agricultural water use in the world would amount to 6,750 instead of 6,400 billion m^3/yr. International trade thus reduces global water use in agriculture by 5%.

Above figures do not differentiate between the use of *green* water (rainwater) and the use of *blue* water (ground and surface water). The global water saving associated with a certain trade flow can refer to either a global *blue* or a global *green* water saving (or a combination of both). Even if there is a net global water loss from a trade relation, there might be a saving of blue water at the cost of a greater loss of green water or vice versa. From an economic point of view, there is a substantial difference between blue and green water saving, because the opportunity costs are generally much higher for blue water than for green water. As a result, trade associated with a blue water saving but a greater green water loss could still be efficient from an economic point of view.

The downside of virtual-water trade as a solution to water scarcity

Saving domestic water resources in countries with relative water scarcity through virtual-water import (import of water-intensive products) looks very attractive. There are however a number of drawbacks that have to be taken into account. First, saving domestic water through import should explicitly be seen in the context of the need to generate sufficient foreign exchange to import food that otherwise would be produced domestically. Some water-scarce countries in the world are oil-rich, so they can easily afford to import water-intensive commodities. However, many water-scarce countries lack the ability to export energy, services or water-extensive industrial commodities in order to afford the import of water-intensive agricultural commodities. Second, import of food carries the risk of moving away from food self-sufficiency. This plays an important role in the political considerations in countries such as China, India and Egypt (see, for instance, Roth and Warner, 2007). Third, import of food will be bad for the domestic agricultural sector and lead to increased urbanisation, because import reduces employment in the agricultural sector. It will also result in an economic decline and worsening of land management in rural areas. Fourth, in many water-scarce developing countries, where an important part of the agriculture consists of subsistence farming, promoting food imports may threaten the livelihoods of those subsistence farmers and reduce access to food for the poor. Finally, increases in virtual-water transfers to optimise the use of global water resources can relieve the environmental pressure on water-scarce countries but may create additional pressure on the countries that produce the water-intensive commodities for export. The potential water saving from global trade is sustainable only if the prices of the export commodities truly reflect the opportunity costs and negative environmental impacts in the exporting countries.

What international trade rules would contribute to a better use of the world's scarce water resources?

The principles of product transparency and non-discrimination

The basis for well-informed consumer behaviour, governmental policy and company strategy is product transparency. The 'product-transparency principle' requires that all relevant information about a product is publicly available, including both information about the product as it appears and information about how it is produced. When we limit ourselves here to how a product relates to the use of freshwater, relevant information may include for instance answers to questions such as: how much water was consumed to make the product in the different stages of its supply chain, how much water was polluted, what type of pollution, does the water consumption or pollution take place in areas where water is relatively scarce and already polluted beyond acceptable limits, are downstream users or ecosystems negatively affected, could the water consumed have been used for an alternative purpose with a higher societal benefit, etc. Products may often look alike – same colour, smell, feel, taste, quality – but nevertheless they may be quite different. Every product has a unique history. The origin of the ingredients may differ as well as the production circumstances of the ingredients. A beverage like cola contains sugars which can come for instance from sugar beet, sugar cane or maize (high-fructose maize syrup). The crop may be grown with irrigation water from the overexploited Ogallala Aquifer beneath the Great Plains in the United States or under rain-fed conditions in a water-abundant part of Europe. In other words, one bottle of cola is simply not equal to another. Two products can have a similar appearance, but a different history. Production circumstances can vary among countries, but also within countries; differences can exist between brands, but also within brands and even between different batches of otherwise precisely the same product. From a water-footprint perspective, one may like to discriminate between seemingly similar goods, based on the different impacts the goods have on freshwater resources. Chapagain et al. (2006b) show, for example, how the water footprint of cotton consumed in Europe strongly depends on the region of origin (Figure 1.1). Cotton from Uzbekistan and Pakistan, for example, has a relatively large water footprint on blue water resources and can be associated with the desiccation of the Aral Sea and intensive use and pollution of the Indus river, respectively.

An important principle used in the context of international trade negotiations is the 'non-discrimination principle'. This principle says that the international trading system should be without discrimination, which means that a country should not discriminate between its trading partners nor between its own and foreign products (WTO, 2008). A key question to be posed in this context is what are the criteria to evaluate whether two goods can be called similar. According to the non-discrimination principle, one may not discriminate between cotton from one and cotton from another country or between beef from one and beef from another country. But what does the principle say if it appears that two seemingly similar products are not similar after all? Discrimination is considered unfair when products are similar, but discrimination is quite natural when products are not similar.

Fair international trade rules should include a provision that enables consumers, through their government, to raise trade barriers against products that are considered unsustainable, or more in particular, in the context of this paper, are kept responsible for harmful effects on water systems and indirectly on the ecosystems or communities that depend on those water systems. In practice, this means that the non-discrimination principle would hold only for similar products that are considered also similar in terms of the existing impacts along their life cycle. It would imply that a country can favour import of a certain product from a country that can guarantee that the product's water footprint is not located in catchments where environmental flow requirements are violated or where ambient water quality standards are not met. This preference would have to hold – according to the non-discrimination principle – for all countries that can give that guarantee. Such guarantee can be provided only when proper arrangements for product transparency are in place. The favour, however, would not necessarily hold for countries that cannot provide that guarantee.

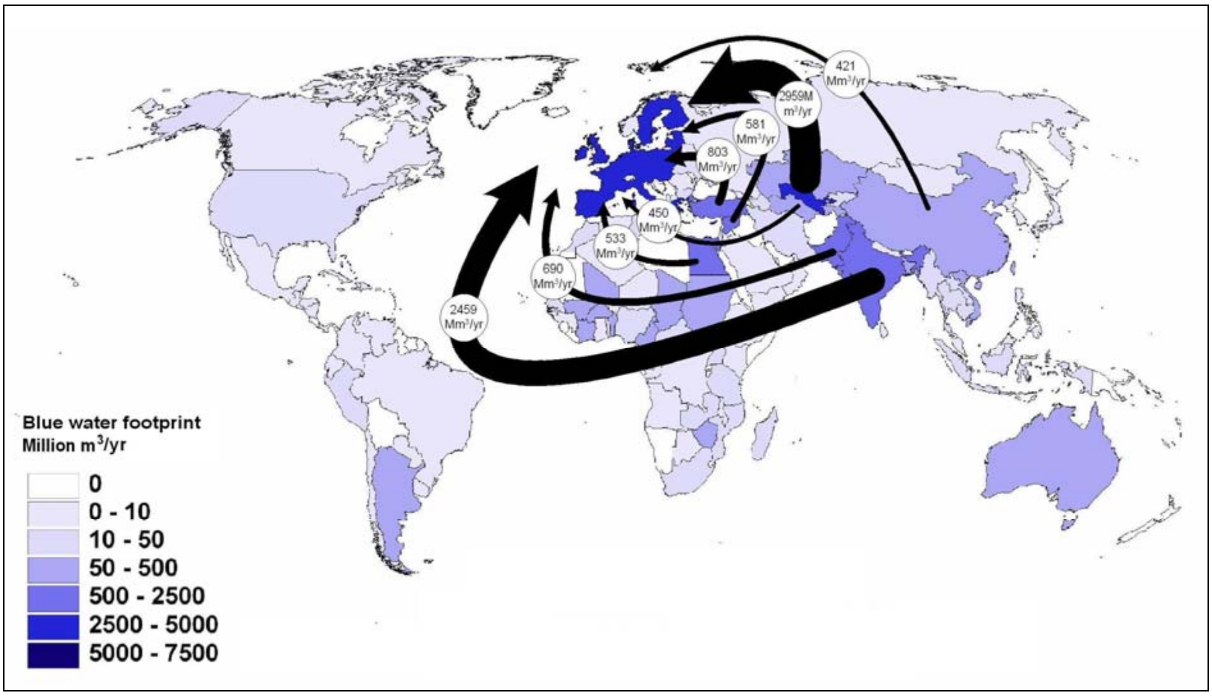

Figure 1.1. The global water footprint of cotton consumption in the European Union. Source: Chapagain et al. (2006).

When arrangements for product transparency in a particular country are in place, it can occur that one set of goods of a certain kind from that country does fulfil a set of specified sustainability criteria, while another set of goods of the same kind does not. In that case, another country may be willing to have free trade with respect to the first set of goods, but to raise trade barriers with respect to the other set of goods. It seems justified to allow for such arrangements in international trade rules. Countries can either choose to agree on shared sustainability criteria, which can then be included in an international trade agreement, or they can leave the formulation of such criteria to each country separately. The former situation may be preferable, because it creates equity and security on the market, but it will be at the cost of national sovereignty to quickly respond to new developments and adapt criteria. Besides, countries may have highly divergent opinions about what criteria should be chosen. Anyhow, trying to agree on shared criteria for product sustainability can be part of international negotiations. This should be in a different context than the World Trade Organization, because the WTO limits itself to trade negotiations and refrains from negotiations on environmental protection. For environmental protection, the WTO refers to multilateral environmental agreements formulated in other international settings. According to WTO rules, a trade dispute that falls under a certain multilateral environmental agreement signed by two conflicting countries, should be settled using the environmental agreement.

The imbalance between international trade agreements and international agreements on sustainable water use

In the perspective of the WTO, 'free trade' is not at odds with 'green trade'. National governments have negotiated WTO rules voluntarily. Similarly, national governments negotiate and agree on international environmental agreements. If a dispute arises over a trade action taken under an environmental agreement, and if both sides to the dispute have signed that agreement, then they should try to use the environmental agreement to settle the dispute. However, if one side in the dispute has not signed the environmental agreement, then the WTO would provide the only possible forum for settling the dispute (WTO, 2008, p.67). Besides, it matters whether an international agreement contains rules that relate to trade or not. As Neumayer (2004) observes, most regional or international environmental agreements do not contain any trade-restrictive measures. As a result, these environmental agreements will be irrelevant, i.e. ignored, when settling a trade dispute. In the case an international environmental agreement is absent and where a trade barrier is raised with reference to *national* environmental legislation, it will again be the WTO to settle the dispute. Historic evidence shows that free trade rules agreed internationally within the context of the WTO go beyond environmental protection rules set by national governments or international environmental agreements not signed by one of the parties of the dispute. According to the WTO, if trade barriers could be raised with reference to national regulations, "then any country could ban imports of a product from another country merely because the exporting country has different environmental, health and social policies from its own. This would create a virtually open-ended route for any country to apply trade restrictions unilaterally – and to do so not just to enforce its own laws domestically, but to impose its own standards on other countries" (WTO, 2008, p.70).

Internationally binding agreements on sustainable water use or, more particularly, on 'sustainable water use in the production of goods and services' do not exist. The reason is probably that – as set out in the introduction – freshwater is primarily seen as a local resource, to be managed at the level of a nation or river basin at most. As a result, policies for water governance are always shaped in the form of national legislation, supplemented by international agreements on trans-boundary rivers and agreements on a regional level like in the European Union. This means that whenever trade disputes with reference to freshwater protection arise, the dispute will be settled under WTO and that – with reference to the non-discrimination principle – the outcome will be in favour of free trade and not freshwater protection.

In the international arena, there is no legal basis to discriminate in international trade based on environmental product standards. This is a fundamental imbalance in the area of international agreements. In the WTO, international trade rules do not necessarily go beyond international environmental agreements, but in case of absence of the latter, the international trade rule of non-discrimination becomes decisive. The WTO agreements say two important things: "First, trade restrictions cannot be imposed on a product purely because of the way it has been produced. Second, one country cannot reach out beyond its own territory to impose its standards on another country" (WTO, p.66). As many products on the world market have significant impacts on freshwater systems, because their production contributes to the violation of local environmental flow requirements or ambient water quality standards, it is expected that consumers will increasingly request product transparency and it is likely that consumers in some countries will start asking their government to ban imports of products that obviously do not meet domestic sustainability criteria. Yet, it is very unlikely that national efforts to ban products with reference to national standards on sustainable water use will succeed. This raises the question of which instruments are left to national governments to ensure that internationally traded products are based on a sustainable use of freshwater. In the next two sections, three different sorts of possible international arrangements are discussed: an international water pricing protocol, a water label for products, and an international water-footprint permit system.

International Water Pricing Protocol

A major issue when talking about good water governance and international trade is the fact that particularly the international market in agricultural products is heavily distorted. Since 85% of global water consumption occurs in agricultural production (Hoekstra and Chapagain, 2008), this is highly relevant for water. The distortion is related to all sorts of direct and indirect subsidies that agriculture receives in all countries in the world, albeit in different forms per country. This issue is widely known, but most discussion is about direct subsidies to farmers and about export subsidies and import taxes. Much less attention is given to the fact that water as a major input factor to agriculture is generally hugely under-priced. The result is that water is no factor of importance in the establishment of production and trade patterns. This results in perverse trade flows, where water-intensive crops are exported on a large scale from areas where water is highly scarce and overexploited. Free trade will never contribute to optimal production and trade outcomes from a water-perspective as long as water remains so much under-priced.

There is a need to reach a global agreement on water pricing structures that cover the full cost of water use, including investment costs, operational and maintenance costs, a water scarcity rent and the cost of negative externalities of water use (Hoekstra, 2006; Hoekstra and Chapagain, 2008; Verkerk et al., 2008). Without an international treaty on proper water pricing, it is unlikely that a globally efficient and sustainable pattern of water use will ever be achieved. The need to have full cost pricing has been acknowledged since the Dublin Conference in 1992 (ICWE, 1992). A global ministerial forum to come to agreements on this does exist in the regular World Water Forums (Marrakech 1997, The Hague 2000, Kyoto 2003, Mexico City 2006, Istanbul, 2009), but these forums have not been used to take up the challenge of making international agreements on the implementation of the principle that water should be considered as a scarce, economic good. The World Water Forums are not organised under the umbrella of a UN organisation. Alternative forums to initiate and negotiate an international Water Pricing Protocol could be UN-Water or the UN Commission on Sustainable Development (CSD).

It is not sufficient to leave the implementation of the ‘water-is-an-economic-good principle’ to national governments without having some kind of international protocol on the implementation, because unilateral implementation can be expected to be at the cost of the countries moving ahead. The competitiveness of the producers of water-intensive products in a country that one-sidedly implements a stringent water pricing policy will be affected, and this, together with the natural resistance of domestic consumers to higher prices of local products, will reduce the feasibility of a unilateral implementation of a rigorous water pricing strategy. An international protocol on full-cost water pricing would contribute to the sustainable use of the world’s water resources, because water scarcity would be translated into a scarcity rent and thus affect consumer decisions, even if those consumers live at a great distance from the production site. Such a protocol would also contribute to fairness, by making producers and consumers pay for their contribution to the depletion and pollution of water. Finally, such a protocol would shed a fresh light upon the economic feasibility of plans for large-scale inter-basin transfers, since it would force negative externalities and opportunity costs to be taken into account. Full-cost water pricing should be combined with a minimum water right, in order to prevent poor people not being able to obtain their basic needs (Gleick, 1999; Mehta and La Cour Madsen, 2005).

An international water label for water-intensive products

The necessity of product transparency could be translated into a ‘water label’. This term should be understood in a very broad way here, because it could be a label physically attached to a product, but also digital information about a specific product available through internet by scanning its barcode in the shop or at home. Furthermore, it could be a simple quality certification showing whether a product meets a certain set of sustainability criteria (a ‘yes or no’ label), but it could also be a more advanced label with detailed quantitative information on a number of relevant criteria. Introducing such a label would be most relevant for water-intensive products. The label could be introduced first for a few commodities that usually have great impacts on water systems, such as rice, cotton, paper and cane sugar. Given the global character of the rice, cotton, paper and sugar markets, international cooperation in setting the labelling criteria and in the practical application of the water label is a precondition. Consideration could be given to integrating the water label within a broader environmental and equity labelling approach, but this would probably create new bottlenecks for global implementation, so that a first step could be to agree on a separate water label.

If one or a number of countries agree on some sort of water-labelling scheme, it is still unclear how current WTO rules have to be interpreted when a dispute would arise. Consider the case in which a country raises a trade barrier for all countries that do not fulfil the requirements of the water-labelling scheme. Given the decisions made in earlier disputes (consider for instance the so-called tuna-dolphin dispute between the USA and Mexico), the WTO rules are unlikely to lead to acceptance of discrimination of products from another country not fulfilling a certain labelling requirement if that other country has not signed up for the labelling scheme. The WTO stipulates that one country cannot impose its own environmental regulations on another country. However, some commentators have argued that under some conditions it is possible for WTO members to impose environmental regulations on another member (Charnovitz, 2002). Altogether, there is still much ambiguity about the role national environmental standards related to processes and production methods can have in restricting international trade. This underlines the necessity to come to broad international agreements on a water-labelling scheme. Without international agreement, any labelling scheme will be useful for domestic products only and unlikely be effective in restricting trade. If countries agree on an international water label, this label will likely be covered by WTO’s Technical Barriers to Trade (TBT) Agreement, which has been designed to ensure that regulations, standards, testing and certification procedures do not create unnecessary obstacles to trade. This means that the labelling scheme should fulfil a set of conditions set by the WTO.

A broad international water label laid down in an international agreement is thus far from reality. Liberalisation of trade in water-intensive products under WTO makes it more difficult, if not impossible, for countries to take action against products from countries that are considered as undesirable because they either lack transparency or are transparent but do not meet certain domestically defined sustainability standards. Under existing WTO rules, countries have to let products that do not meet production-standards enter the country at the same conditions as similar products that do meet those standards. The only remaining choice is that consumers select themselves in the shop. This choice will be hampered, however, by lack of information, because countries cannot impose a labelling scheme on imported products.

An International Water-Footprint Permit System

The limited availability of freshwater in the world implies a ceiling for humanity's water footprint. The question for the global community is how this global maximum can be transferred to the national or even the individual level. In other words: what is each nation's and each individual's 'reasonable' share of the globe's water resources? And what mechanisms could be established in order to achieve that people do not use more than their 'reasonable' share? Maximum levels of water use to guarantee a sustainable use could be institutionalised in the form of a water footprint permit system (Hoekstra, 2006; Hoekstra and Chapagain, 2008; Verkerk et al., 2008). An international protocol on establishing water footprint permits would be comparable to the Kyoto Protocol on the emissions of greenhouse gases (drafted in 1997, effective since 2005). The Kyoto Protocol is based on the understanding that, to prevent human-induced climate change, there is a ceiling on the maximum volume of greenhouse gas emissions from human activities at the national and global levels.

In an international water-footprint permit system, permits would be issued per nation. Alternatively, the permits can take the form of water-footprint reduction targets compared to a certain reference year or period. Nations would be responsible for translating the targets into national policy in order to meet the target or remain within the permit. Enforcement could be done in the form of penalties when not meeting the agreed targets. Targets would need to be specified for example by water footprint component (green, blue, grey water footprint); they could also be specified by sector or product category.

The Doha Development Round

The WTO rules apply to most products but still exclude or include to a limited extent services and agricultural products. Because 85% of the water consumption in the world occurs in agriculture, concerns with respect to sustainable freshwater use can still be taken into account in the negotiations in the Doha Development Round, the current trade-negotiation round of the World Trade Organization, which started in 2001. Trade in agricultural products is one of the key focus areas of the current negotiations. As follows from above, from a sustainable-water-use perspective it is key that any new rules on international trade in agricultural products include provisions ensuring that efforts to contribute to more sustainable water use behind the products traded are promoted and rewarded.

Discussion

International transfers of water in virtual form are substantial and likely to increase with continued global trade liberalisation (Ramirez-Vallejo and Rogers, 2004). Intensified trade in water-intensive countries offers both opportunities and risks. The most obvious opportunity of reduced trade barriers is that virtual water can be regarded as a possibly cheap alternative source of water in areas where freshwater is relatively scarce. Virtual-water import can be used by national governments as a tool to release the pressure on their domestic water resources. This import of virtual water (as opposed to real water, which is generally too expensive) will relieve the pressure on the nation's own water resources. Besides, trade can save water if products are traded from countries with high to countries with low water productivity. For example, Mexico imports wheat, maize, and sorghum from the USA, the production of which requires 7.1 billion m^3 of water per year in the USA. If Mexico were to produce the imported crops domestically, it would require 15.6 billion m^3 of water per year. Thus, from a global perspective, the trade in cereals from the USA to Mexico saves 8.5 billion m^3/yr. Although there are also examples where water-intensive commodities flow in the opposite direction, from countries with low to countries with high water productivity, the available studies indicate that the resultant of all international trade flows works in a positive direction. We showed that international trade in agricultural commodities reduces global water use in agriculture by 5%. Liberalisation of trade seems to offer new opportunities to contribute to a further increase of efficiency in the use of the world's water resources.

A serious drawback of trade is that the indirect effects of consumption are externalised to other countries. While water in agriculture is still priced far below its real cost in most countries, an increasing volume of water is used for processing export products. The costs associated with water use in the exporting country are not included in the price of the products consumed in the importing country. Consumers are generally not aware of – and do not pay for – the water problems in the overseas countries where their goods are being produced. According to economic theory, a precondition for trade to be efficient and fair is that consumers bear the full cost of production and impacts. Another downside of intensive international virtual-water transfers is that many countries increasingly depend on the import of water-intensive commodities from other countries. Jordan annually imports a virtual-water volume that is five times its own annual renewable water resources. Other countries in the Middle East, but also various European countries, have a similar high water import dependency. The increasing lack of self-sufficiency has made various individual countries, but also larger regions, very vulnerable. If, for whatever reason, food supplies cease – be it due to war or a natural disaster in an important export region – the importing regions will suffer severely. A key question is to what extent nations are willing to take such risk. The risk can be avoided by promoting national self-sufficiency in water and food supply (as Egypt and China do). The risk can be reduced by importing food from a wide range of trading partners. The current worldwide trend, however, facilitated by the World Trade Organization, is toward reducing trade barriers and encouraging free international trade, and decreasing interference by national governments.

The current global trade pattern significantly influences water use in most countries of the world, either by reducing domestic water use or by enhancing it. Future national and regional water policy studies should therefore include an assessment of the effects of trade on water policy. For water-scarce countries, it would also be wise to do also the reverse assessment: study the possible implications of national water scarcity on trade. In short, strategic analysis for water policy-making should include an analysis of expected or desirable trends in international or inter-regional virtual-water flows.

International agreements on the liberalisation of trade in agricultural products – as being negotiated in WTO's ongoing Doha Development Round – should include provisions that promote sustainable water use in agriculture. As yet, it is unclear how such provisions could look like, since the WTO explicitly refrains from making environmental agreements. An imbalance in global trade regulations will be created as soon as free trade agreements are effective while sustainable-product and sustainable-water-use agreements to constrain international trade are not yet existent. This is a serious risk, since no international agreements on sustainable water use or sustainable products do exist or are being prepared.

References

Allan, J.A. (2001a) Virtual water - Economically invisible and politically silent - A way to solve strategic water problems, International Water and Irrigation, Nov: 39-41.

Allan, J.A. (2001b) The Middle East water question: Hydropolitics and the global economy, I.B. Tauris, London, UK.

Chapagain, A.K., Hoekstra, A.Y. and Savenije, H.H.G. (2006a) Water saving through international trade of agricultural products, Hydrology and Earth System Sciences 10(3): 455-468.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G. and Gautam, R. (2006b) The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries, Ecological Economics 60(1): 186-203.

Chapagain, A.K. and Hoekstra, A.Y. (2008) The global component of freshwater demand and supply: An assessment of virtual water flows between nations as a result of trade in agricultural and industrial products, Water International 33(1): 19-32.

Charnovitz, S. (2002) The law of environmental "PPMs" in the WTO: Debunking the myth of illegality, The Yale Journal of International Law 27(1): 59-110.

De Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M. and Molden, D. (2004) Does international cereal trade save water? The impact of virtual water trade on global water use, Comprehensive Assessment Research Report 4, IWMI, Colombo, Sri Lanka.

Gleick, P.H. (1999) The human right to water, Water Policy 1(5): 487-503.

Gleick, P.H. (2004) The myth and reality of bottled water, In: Gleick, P.H. (ed.) The world's water 2004-2005, The biennial report on freshwater resources, Island Press, Washington, D.C., USA, pp.17-43.

Gleick, P.H., Wolff, G., Chalecki, E.L. and Reyes, R. (2002) Globalization and international trade of water, In: Gleick, P.H. et al. (ed.) The world's water 2002-2003, The biennial report on freshwater resources, Island Press, Washington, D.C., USA, pp.33-56.

Greenaway, F., Hassan, R. and Reed, G.V. (1994) An empirical-analysis of comparative advantage in Egyptian agriculture, Applied Economics 26(6): 649-657.

Grote, U., Craswell, E., and Vlek, P. (2005) Nutrient flows in international trade: Ecology and policy issues, Environmental Science and Policy 8: 439-451.

GWP (2000) Integrated water resources management, TAC Background Paper No.4, Global Water Partnership, Stockholm, Sweden.

Haddadin, M.J. (2003) Exogenous water: A conduit to globalization of water resources, in: A.Y. Hoekstra, Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Value of Water Research Report Series No. 12, UNESCO-IHE, Delft, pp. 159-169.

Hoekstra, A.Y. (ed.) (2003) Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Delft, The Netherlands, 12-13 December 2002, Value of Water Research Report Series No.12, UNESCO-IHE, Delft, The Netherlands.

Hoekstra, A.Y. (2006) The global dimension of water governance: Nine reasons for global arrangements in order to cope with local water problems, Value of Water Research Report Series No.20, UNESCO-IHE, Delft, The Netherlands.

Hoekstra, A.Y. and Chapagain, A.K. (2007) Water footprints of nations: Water use by people as a function of their consumption pattern, Water Resources Management 21(1): 35-48.

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

Hoekstra, A.Y., and Hung, P.Q. (2005) Globalisation of water resources: International virtual water flows in relation to crop trade, Global Environmental Change 15(1): 45–56.

ICWE (1992) The Dublin statement on water and sustainable development, International Conference on Water and the Environment, Dublin.

ITC (2004) PC-TAS version 1997-2001, Harmonized System, CD-ROM, International Trade Centre, Geneva, Switzerland.

Liao, Y., De Fraiture, C. and Giordano, M. (2008) Global trade and water: lessons from China and the WTO, Global Governance 14: 503-521.

Ma, J., Hoekstra, A.Y., Wang, H., Chapagain, A.K. and Wang, D. (2006) Virtual versus real water transfers within China, Philosophical Transactions of the Royal Society of London B 361(1469): 835-842.

Maclean, J.L., Dawe, D.C., Hardy, B. and Hettel, G.P. (2002) Rice almanac: Source book for the most important economic activity on earth, International Rice Research Institute, Los Baños, Philippines.

McIsaac, G.F., David, M.B., Gertner, G.Z. and Goolsby, D.A. (2001) Eutrophication: Nitrate flux in the Mississippi river, Nature 414(6860): 166-167.

Mehta, L. and La Cour Madsen, B. (2005) Is the WTO after your water? The General Agreement on Trade in Services (GATS) and poor people's right to water, Natural Resources Forum 29: 154-164.

Meybeck, M. (2004) The global change of continental aquatic systems: dominant impacts of human activities, Water Science and Technology 49(7): 73-83.

Neumayer, E. (2004) The WTO and the environment: Its past record is better than critics believe, but the future outlook is bleak, Global Environmental Politics 4(3): 1-8.

Nriagu, J.O. and Pacyna, J.M. (1988) Quantitative assessment of worldwide contamination of air, water and soils by trace metals, Nature 333: 134-139.

Oki, T. and S. Kanae, (2004), Virtual water trade and world water resources, Water Science and Technology 49(7): 203-209.

Ramirez-Vallejo, J. and P. Rogers (2004) Virtual water flows and trade liberalization, Water Science and Technology 49(7): 25-32.

Ricardo, D. ([1817] 2006) On the principles of political economy and taxation, Cosimo, New York, USA.

Rogers, P., Bhatia, R., and Huber, A. (1998) Water as a social and economic good: How to put the principle into practice, TAC Background Papers No. 2, Global Water Partnership, Stockholm, Sweden.

Roth, D. and Warner, J. (2007) Virtual water: Virtuous impact? the unsteady state of virtual water, Agriculture and Human Values 25(2): 257-270.

Sanchez, P.A. (2002) Soil fertility and hunger in Africa, Science 295(5562): 2019-2020.

Savenije, H.H.G. (2002) Why water is not an ordinary economic good, or why the girl is special, Physics and Chemistry of the Earth 27:741-744.

Stocking, M.A. (2003) Tropical soils and food security: The next 50 years, Science 302(5649): 1356-1359.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D. and Swackhamer, D. (2001) Forecasting agriculturally driven global environmental change, Science 292(5515): 281-284.

Verkerk, M.P., Hoekstra, A.Y. and Gerbens-Leenes, P.W. (2008) Global water governance: Conceptual design of global institutional arrangements, Value of Water Research Report Series No.26, UNESCO-IHE, Delft, The Netherlands.

Verma, S., Kampman, D.A., Van der Zaag, P. and Hoekstra, A.Y. (2009) Going against the flow: A critical analysis of inter-state virtual water trade in the context of India’s National River Linking Programme, Physics and Chemistry of the Earth 34: 261-269.

Wichelns, D. (2001) The role of ‘virtual water’ in efforts to achieve food security and other national goals, with an example from Egypt, Agricultural Water Management 49(2): 131-151.

Wichelns, D. (2004) The policy relevance of virtual water can be enhanced by considering comparative advantages, Agricultural Water Management 66(1): 49-63.

Wichelns, D. (2010) Virtual water: a helpful perspective, but not a sufficient policy criterion, Water Resources Management, 24(10): 2203–2219.

WTO (2008) Understanding the WTO, Fourth edition, World Trade Organization, Geneva, Switzerland.

Yang, H., Reichert, P., Abbaspour, K.C., and Zehnder, A.J.B. (2003) 'A water resources threshold and its implications for food security' Environmental Science and Technology 37:3048-3054.

Yang, H., Wang, L., Abbaspour, K.C. and Zehnder, A.J.B. (2006) Virtual water trade: an assessment of water use efficiency in the international food trade, Hydrology and Earth System Sciences 10(3): 443-454.

Yang, H., Wang, L., and Zehnder, A. (2007) Water scarcity and food trade in the Southern and Eastern Mediterranean countries, Food Policy 32:585-605.

2. The role of those who produce food and trade it in using and 'trading' embedded water: What are the impacts and who benefits?

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Abstract

The *main* purpose of the analysis is to identify *who owns* what, *who does* what, *who controls* what and *who gets* what - in the strategically important global economy of food production and trade. This analysis will *first* highlight the key players in the international political economy of global and local water security. It will identify the players in civil society, in government, in the private sector and civil movements who engage in *agricultural production*, in managing *agribusiness and food processing* and in *food consumption*. *Secondly*, it will be shown that it is individuals and organisations in the *private sector* that produce, process, deliver and finally consume food. They own, control and endure the risks and gain the benefits of using and misusing natural resources on the farms and in the markets, in which food is produced, traded and consumed. *Thirdly*, the focus will be on the global food trade and the operations of the dominant players, namely the small number of global traders that ship the major staples - wheat, maize, soya and sugar – across the world. *Finally*, there will be a review of the policy relevance of this global political economy to the regulation of those in the food supply chain who steer the behaviour of its participants to use and manage water in ways that are sustainably intensifying.

Introduction – the food supply chain

The purpose of this chapter is to highlight the role of the private sector and consumers in allocating the use of water in agriculture in the production of food, in trading it, processing it, retailing it and consuming it. Between 80 and 90 per cent of the water used by society is used and abused in this supply chain. The relationship between water and food production is elemental. But unfortunately invisible. There will be an analysis of *who owns* what, *who does* what, *who controls* what and *who gets* what - in the strategically important global economy of food production and trade.

If the vast volumes of water embedded in the food supply chain are to be managed in ways that take into account the value of water and water environmental services the key agents in this supply chain must manage vital elements of the supply chain differently. Farmers will be shown to be the key agents in achieving water security because farming uses so much water. Food consumers will be shown to have the most potential to influence the volumes of water embedded in the supply chain. Environmental and human health activists are shown to be a major source of wisdom and very important indeed in getting society, corporations and regulatory agencies to adopt new ideas that lead to environmental stewardship and the proper valuation of scarce renewable natural resources. Brand and Non-brand corporations are shown to have a major potential role in leveraging market behaviour deep in the supply chain. Regulation by the public sector will be shown to have had limited influence at both the sub-national level and particularly at the international level to achieve the sustainable intensification of water. The public sector agencies have had limited influence because of the very predominant private ownership of the inputs and of the market institutions – both in the sense of market rule-making and the operation of market organisations.

The introductory analysis will *first* highlight the key players in the international political economy of global and local water security. It will identify the players in civil society, in government, in the private sector and civil movements who engage in elements of the food supply chain. These players engage in *agricultural production*, in managing *agribusiness and food processing* and in *food consumption*. *Secondly*, it will be shown that it is individuals and organisations in the *private sector* that produce, deliver and finally consume food. They own, control and endure the risks and gain the benefits of using and misusing natural resources on the farms, and in the markets, in which food is produced, traded and then consumed.

For thousands of years markets have proved to be a very effective - if rough and ready - means of combining resource inputs - natural, human, capital and organisational - to meet societies' needs and preferences. But the principles of profit and competition that inspire the market have not, until recently, included consideration of social and environmental impacts. In practice markets have proved to be both casually and ruthlessly blind to social and environmental equity. This is particularly the case at the global level of international trade where producers and consumers are at distant ends of a very long supply chain. Consumers are unaware of the impacts their consumption imposes on natural systems. Ideally markets have willing buyers and willing sellers and all of them are equally well informed. In practice markets are distorted by extreme asymmetric knowledge and can be made seriously unfair by alliances between some private sector players and some over-powerful states (Sauer et al., 2003; Chambers et al., 2009). This last condition is particularly relevant to this analysis of global water and food security achieved via international trade.

Markets provide for society the strategic and elemental service of food security for consumers but at a price for the weak producers and with brutal outcomes for some farmers, as well as for many farm workers. Markets are almost always also associated with environmental costs. History is scarred by the society wrecking battles that have had to be fought to reverse and remedy the excesses of the market and the state. Two hundred years ago, even in the era of the American civil war, we would have been speaking about the excesses of slavery in the food supply chain. This social crime was enabled by the market and appreciated by some states and their sugar consumers. People can be blind and unaware. In the late 19th century unions had to be invented via collective action and in the face of violent reactions to give labour a voice to ensure its fairer participation in unfair market systems. The circumstances that had to be contended had evolved in a blind alliance between market and state. A century later the green movement has been giving the environment a voice but only for the past four decades. *Thirdly*, the focus will be on the global food trade and the operations of the dominant players, namely the small number of global traders that ship the major staples - wheat, maize, soya and sugar – across the world. These are the non-brand corporations which include ADM, Bunge, Cargill and Dreyfus. It will be shown that their knowledge of the global trade in staple food commodities enables them to be very influential players in the global trading system but only if they adopt a wider definition of the operation of capitalism being promoted by Porter and Kramer (2010). Their knowledge does not extend to knowing about their hugely important role in facilitating global virtual water 'trade'. The human condition is to be blind to the elephant in the room. But as will be shown it is not unusual to be blind to being the elephant in the room.

Finally, the role of *consumers* in driving the demand for food and water will be highlighted. The policy relevance of consumers in the global political economy in moderating and regulating the food supply chain is very important. The behaviour of consumers determines the ways that water is allocated and managed and whether this management is sustainably intensifying. We cannot avoid intensifying but we must intensify sustainably. Consumers and traders are both unaware elephants. Getting the former to become aware is a major and enduring problem. The non-brand global traders are moving quickly even as these sentences are being written.

The sustainable intensification context

There is not space in a single chapter to provide details on how the gains in water productivity have been achieved through the industrialisation of agriculture. In rainfed farming, where improvements in water use efficiency in farming are easier to measure than those in irrigated farming the gains have been extraordinary. There was a threefold increase in the productivity of water in rainfed wheat production in north-west Europe between 1800 and 1950. And a further trebling by 1990. Farmers were getting ten times the water productivity after two centuries through the intensified use of other inputs – especially of energy, fertilisers, improved seeds and agronomy. Intensification achieved a tenfold increase in water productivity over 200 years. Albeit not always sustainably. Those farmers who are currently achieving low returns to water elsewhere need to be touched by sustainable and intensifying practices. For example the farmers of Sub-Saharan Africa producing between half and one tonne per hectare of grain need to have access to inputs and infrastructures that will increase their rainfed land productivity.

The intensification of rainfed farming can go too far. Excessive use of inputs negatively impacts the soil environment and also pollutes soil water, surface water and groundwater on which crop production depends. But rainfed farming is less vulnerable than irrigated farming as irrigated crop production is very high risk environmentally and economically. Once established the supply of irrigation water becomes embedded in livelihoods that cannot be undone because the social and political prices would be too high. The mitigation of poverty and other economic solutions which irrigation promises in the short run bring impossible social and political challenges in the long run. Those who have become dependent on irrigated livelihoods fight to keep what – for those who want to see - is an irreversible destruction of blue [2] water resources. Irrigators always run

[2] Blue water here, is the water that can be pumped and conveyed from surface water sources and from sub-surface groundwater and used in crop and livestock production as well as in food processing further along the supply chain. Blue water can be used for a wide range of agricultural, non-agricultural and social uses. Green water is the water that remains long enough in the soil profile to support crops evapotranspiration. Unlike blue water which has numerous economic uses green water can only be used for one environmental and one economic use. It can support both natural vegetation and rainfed crops. Crops can be raised with green or blue water. About 70% of global food production derives from green water. About 80% of the food traded was raised from green water.

out of water. At first occasionally. Ultimately the surface and groundwater resources are used to the detriment of the environment and society. Irrigation has dried up one of the biggest inland seas in the world in Central Asia, at least one major river in the US and another in China and many in the Middle East. Capitalism and communism have proved to have the same self-destructive tendencies. *Hesitate to irrigate* is an impossible but wise precautionary approach for those who may be contemplating it.

The problems associated with the intensification of irrigated farming are so common that they can be regarded as normal. Irrigators encounter all the problems associated with the intensification of all farming. They alone encounter the problem of running out of water. Irrigators not only always run out of water they also get into competition with neighbouring, and sometimes distant, economic activities. They are the main competitors over water that could be used to protect the environmental services of water on which we all collectively depend.

The gains from the intensification of crop and livestock production are absolutely fundamental to local and global water and food security. Farming, the first element of the supply chain, is where massive quantities of water are diverted from the blue water environment. It diverts into crop and fodder production even greater quantities of green water on farms where it would otherwise support natural vegetation. In current global circumstances where the mobilisation of new water is impossible or problematic it is essential that gains by intensification in the productivity of water at the beginning of the food supply chain also enhance the sustainability of farming systems. Where possible the water resource benefits of intensification - namely the reduction of water extraction and the availability of some of the water formerly used to produce crops - should result in the return of this water to the water environment. It is the understandable instinct of farmers to devote the water saved by intensification to the production of additional crops. It is argued here that society's collective benefit would be achieved by the promotion of the principle of the stewardship of water over that of using 'saved' water to produce additional crops.

The political-economy context

The purpose of the analysis is to identify *who owns* what, *who does* what, *who controls* what and *who gets* what - in the strategically important global economy of food production, trade and consumption. This approach is deployed in order to identify the agents and forces that shape the way water resources are captured and managed in the major water-using sector – agriculture. The intent is to highlight the extent to which agri-trade and other actors in the food supply chain nurture, or not, water valuing and water saving practices in the supply chain. These players are not yet fully aware of their pivotal role in 'trading' virtual water [3] – although they are rapidly becoming aware. But being unaware of water content in commodities and of the value of aware will be shown to be normal.

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[3] The explanatory insights of the virtual water concept have been usefully critiqued by a number of economists (de Fraiture et al., 2004; Wichelns, 2010; Frontier Economics Network, 2008 ; Le Vernoy, 2010).

An underpinning assumption of this analysis is that there are four elements of society and its politics that – if they engage constructively – bring about advances in well-being, sustainable intensification of natural resource use as well as security for economies, consumers and the environment. Figure 2.1 shows these four social solidarities. Top left there is everyone at breakfast time in civil society. There are three social solidarities that do things to individuals and groups in civil society. Top right are the public sector institutions of the government sector including the state Bottom left are the institutions of the market. They are the *entrepreneurs* in this four way system of organising society and its political economies. Bottom right are the non-governmental activist bodies advocating social, economic and environmental justice. They include the trades unions and the institutions inspired by the ethics of the world's religions. These are the *auditors* of society.

Figure 2.1. The four social solidarities – that is the four ways of life or ways of organising – which society operates and interacts over interests, policies and outcomes. They differ in the extent to which they own, do, control and get what.

Civil Society Consumers	**The State (.GOV)** The Public Sector – Government
The Market (.COM) The Private Sector	**Civil Movements (.ORG)** Sub-national, National & International NGOs and Unions

In Figure 2.2 *Civil Society* and the *Market* – on the left half of the diagram – are shown to be the locus of the food supply chain. This supply chain is wholly located in civil society and the market – that is in the private sector. Included in this civil society/market universe are the ten per cent or so of the world's population who are the food producers as *subsistence farmers*. They are not involved in the market. They produce food but this production achieves very low levels of water productivity and the output does not enter the market. Also shown are the approximately 50% of the world's population who live in *urban places*. They consume over 50% of the world's food but they do not produce food and depend on the food supply chain to provide it. Also shown are the *family farmers* some of whom are partly commercial and others wholly commercial (Weiss, 2007). In addition there are the *corporate farmers* in the industrialised and BRICs economies who are wholly in the market sector, as are the remaining players in the supply chain – the *food commodity traders*, the *food processing corporations* and the *super-markets* and other retailers. Embedded in the chain are the organic producers and agents who resist the unsustainable neo-liberal forces of industrial farming and the sometimes, selectively socially and environmentally damaging global food chain systems.

Figure 2.2 shows those who deliver what to whom in the very water intensive food supply chain. It shows that it is *farmers, commodity traders, the food manufacturing corporations*, as well as the *supermarkets* and the *consumers* who need to know about the actuality of sustainable intensification. They are the agents who could bring about the sustainable intensification of food production and consumption so that food and water security can be ensured in all locations by the global political economy.

Figure 2.2. A general analytical structure of the agents/social solidarities involved in the food supply chain, from food production through to food consumption.

Food supply chain

All private sector & market owned, controlled and benefit receiving CIVIL SOCIETY	Public sector & civil movements - exert some control .GOV
Subsistence farming families	
Urban food consumers	Public sector interventions Subsidies, incentives, regulation & potential regulation
Small-holder farmers - some market participation	
.COM **Market owned, run, controlled & benefits received**	**. ORG** **Minor influence but immense potential influence**
Commercial farmers – small scale	
Corporate farmers	Voices of social, economic & environmental, justice activists
International food commodity traders – Non-Brand - ABCD	
Agri-Business – Brands – food commodity processing & trading	
Supermarkets and food retailers	

The key agents in the food supply chain

It is because agriculture accounts for between 80 and 90 per cent of the water used by society that we are focusing on food production and on those who produce and deliver it. Most economies cannot meet their food needs with their own water endowments. They have to ‘access’ water embedded in commodities via trade and are dependent on international trade for their food and water security.

Ignorance of these processes has been universal (Allan, 2011; Goleman, 1997). All the private sector players in this supply chain – remember, all of them are in the private sector - who do the food production, the food trading, the food processing and the food retailing have been ignorant of their vital role in addressing hot-spots of water scarcity. They are also ignorant of their roles in coping with the existential strategic challenge of achieving *global water security*. Awareness is changing. But so far only a few players have become aware. In this market system commodity prices are misleading as they do not capture the actual costs of delivering water nor the costs endured by the water environment consequent on the ways that water resources are currently managed by farmers. A major purpose of this chapter is to show that food commodity prices - mediated by existing market political economy processes - cannot provide price signals to change consumption behaviour. Water resource stewardship consistent with sustainable intensification will only be achieved in the short term by non-market political economy measures. These include regulation and the education of the actors who operate in the whole length of the food supply chain. New directions will require the adoption of shared values on how to achieve sustainable intensification by all four elements of society – civil society, the state, the market and the civil movement auditors.

The policy-relevant question being asked is how do the players *value water* who determine how much water is being used in the food supply chain and how effectively? And how can they be influenced individually or collectively, through their ownership of, their control of, and their profiting from participation in the supply chain, contribute to the *sustainable maximisation of the overall productivity of water*? In addition how can they be encouraged to take a *leadership* role in improving social and environmental equity with respect to water. Their customers are becoming increasingly aware of these inequities?

Farmers who irrigate determine the levels of blue water withdrawn from the blue water environment. *Other farmers* determine the ways that the water in the soil profile – green water - is captured to raise crops and livestock. Many farmers use both green and blue water. The ways farmers combine water and other farm inputs determines first, crop yield, secondly, the impact of their activities on the water environment and thirdly, the economic and environmental sustainability of their livelihoods. Water productivity is directly related to yield. A subsistence farmer uses four inputs – labour, land, water and seeds and gets very low yields. A farmer in an industrialised economy uses many inputs, perhaps 104 or even 1004, and can achieve in some circumstances ten times the crop yield and ten times the water productivity. This soil water which both subsistence and high input farmers use – accounting for about 70% of global food production - would otherwise have supported natural vegetation, wild-life and possibly livestock.

Global food commodity traders handle farm outputs and 'convey' the virtual water embedded in the food produced by farmers unaware until very recently of the global water securing function that they have been performing. They wonderfully fix the food and water security of the world's net food importing economies and their increasing food and water demands. There must be over 150 net food importers amongst the 210 economies in the world. This trade accounts for about 15% of global food production. A small number of crops – wheat, maize, soya and sugar – raised mainly from soil water on rainfed farms account for about 70% of the virtual water embedded in food commodity trade (Aldaya et al., 2010). Soil or green water is very important indeed in current and future global water security.

Agri-business and supermarket corporations are also major agents in the food supply chain. They are currently the most water resource aware players in the food supply chain although they have been encouraged into this position by international NGOs and some activist water scientists (WWF and SAB Miller, 2009; Waterwise, 2007). Emblematic events (Hajer, 1995), such as the classic example of the closure of the Coca-Cola plant at Plachimada, in Kerala, India in 2004, can change collective social and corporate behaviour. In this case the behaviour of whole industries has been changed - such are the reputational ramifications. The closure occurred because local farmers backed by the community and local *panchayat* officials persuaded most of the world's media that the bottling plant had depleted and polluted the local groundwater. This highly politicised -even globalised media episode - still rumbles on as any internet search shows. Such events have accelerated corporate awareness of the dangers of competing for water where water rights and local expectations are not well understood. One of the outcomes of such events is that the value of water and its role in corporate supply chains has motivated corporations to grapple with the problem of how they can reduce the size of the water footprints in their operations. Dealing with their own water footprints has been challenging but addressable. They quickly found that the big challenges and the essential beneficial changes in practice lie in the parts of the supply chain managed by suppliers and over which they have little or no influence. Their transactions with suppliers up the supply chain are mediated by super-market pricing that is blind to uncosted inputs. They are not mediated by the value, nor the scarcity, nor the environmental impacts of inputs such as water. These are all unpriced.

The market principles of profit and competition that drive the private sector have not so far inspired the development of practical or effective tools that could influence the water using practices of the numerous other players in the long supply chains. Responding to the awareness of water insecurity threats as well as to the evolving preferences of consumers has been easy for the brand corporations in the generally rather easy tasks of addressing their in-house water using practices. Despite the major implicit challenges - conveying newly emerging consumer preferences about social and environmental justice, to the farmers and traders who supply these corporations, will be an enduring element in their future strategizing of creating shared values.

Some analysts are now arguing that the concepts of social and environmental responsibility have to be mainstreamed in business. Porter and Kramer (2010) make the claim that capitalist organisations are best able to operationalize the new socially and environmentally aware agendas. The global brands are very deeply involved in many fundamental economy and society securing activities and services that are integral to food provision. They are also organisationally capable and better capitalised than the other solidarities – the state, the NGOs and civil society. But there is not yet strong evidence that many are questioning the assumptions that growth is the only way forward for capitalist economies (Simms et al., 2010; Woodward et al., 2006).

Finally *consumers,* at the last stage of the food supply chain, are not aware at all of the vital role their diet preferences play in determining the demand for food and therefore for water. They are certainly one of the unaware elephants in the room and it seems likely that the dangerous ignorance will endure. Some consumer voices amplified by the international NGOS and the Water Footprint Network (2011) have moved the brand corporations to be water resource aware. For example, Nestlé, Unilever, SAB Miller, Coca Cola, Pepsi, Walmart, Tesco and many others have become aware. But most consumers have not yet understood they are the main drivers of unhealthy, wasteful and environmentally damaging water resource use. Farmers and farming are too far away on the very long food supply chain. The alliance between anti-slavery advocates and sugar and cotton consumers ended the trade in slaves and gradually reduced the practice. It will take just as long for society and its marketeers to re-evaluate the environmental justice of misusing water resources. The loss of reputation - not to speak of falling sales - are neuralgic issues for chief executive and chief finance officers and they can galvanise re-evaluation processes in new frenzies of risk awareness which characterises late modern societies (Beck, 1999; Giddens, 1990).

Farmers, global food commodity traders, agri-business and supermarket corporations and consumers are being highlighted because they are the agents who could change the way water is used and especially how much water is used in the food commodity supply chain. Collectively they could change mindsets on how the essential input of water is valued. They could do this more effectively if there were more concepts and terms informing the collective understanding of the invisible water using processes underpinning the supply chain. So far this language has proved to be based on the useful but by no means comprehensive concepts of virtual water (Allan, 2003) and water footprints (Hoekstra and Chapagain, 2009).

In the past decade there has been a growing awareness that the water and food security of perhaps 150 out of the 210 economies in the world depends – to a significant and strategic extent - on the *food production / food trade nexus* (Allan, 2010). In other words most economies are net importers of food commodities. In addition it is becoming increasingly evident that a factor contributing to water and food insecurity is the behaviour of consumers in OECD economies through their poorly informed consumer food choices and in the ways these consumers waste food (Quested et al., 2009). Irrational food consumption plus food waste could account for 50% of the total water embedded in OECD food. These unwise *food consumption choices* are also very bad for human and environmental health (Lang et al., 2009). Almost as serious in terms of impacts on global water resources as food choice is *food waste*. In developing economies food waste is also a serious problem. It occurs between the farm gate and the market. All of these activities account for about 30% of the food commodities produced in these economies (WRAP, 2009; Lundqvist et al., 2008; Lundqvist, 2010; Rabo Finance India, 2007).

The food supply chain in a global market - ensures food and water security

It is important to repeat that the water-food-trade nexus operates wholly in the private sector. Private sector production and marketing systems handle all the direct inputs. Society will have to *control* markets if the 'wicked problems' [4] brought about by society and its markets are to be addressed. Wicked problems are as integral to markets as the virtues which solve societies' problems. With few exceptions *farmers* operate in the private sector and are part of market systems – owning their land and they assume their water (Allan, 2010). They are correct in assuming they own the green water that exists in the soil profiles of their farms after it rains. They have substantial control of the blue water that can be pumped from the groundwater in the aquifers beneath their farm - until they discover that their neighbours have taken it first. They tend to be aware they have less control over the blue water that they take from surface waters in rivers and lakes which is usually delivered to them by infrastructures provided by public or social investments. These surface waters are evident to all the users and access is evidently determined by whether one is upstream or downstream, or powerful or both. A well regulated transparent system that gives priority to resource stewardship as well as to production would deliver sound water allocation and management but such systems are the exception (Backenburg et al., 1997). The wealth of literature identifying and promoting regulatory institutions shows that the industrialised countries have observers alert to the need to install them (Kaika, 2003; Kalis et al., 2001; Livingston et al., 2005).

Groundwater resources are much more difficult to understand and monitor. The green water in the soil profile comes at Nature's whim, is normally not monitored and is not shared. Blue water can to some extent be monitored although it is exceptional to do so in agriculture and when it is farmers can, and often do, frustrate the intent of regulators to monitor. Blue water can also be engineered to suit the convenience of users. Its absence is evident when water courses and aquifers run dry, often as a consequence of unfair sharing. But notionally fair sharing can be just as damaging environmentally if the environment does not have the chance of gaining a share. Which it rarely does once water is allocated to the economy. Most important of all, however, is the unfortunate condition that blue water is not valued by farmers in accord with its costs of *sustainable* delivery.

Farming is still the livelihood or the life support system of half of the world's population, which is over three billion souls – or about 700 million farmers. They manage most of the world's water and often produce very low yields and therefore very poor economic returns to water. They are both numerous and diverse. They can own

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[4] A wicked problem is the outcome of an earlier attempt to address an urgent problem in uncertain circumstances. Societies have to cope with the wicked outcomes of initiatives taken by market and government initiatives – sometimes mutually conceived – that lead to new and much bigger problems. The way big-oil – abetted by major neo-liberal governments – responded to the 1970s oil price spikes is the classic example. The solution identified by a market/government alliance – to find and market more oil at prices blind to environmental impacts - has led to a much bigger and long lasting problem exacerbated by the procrastination in developing benign solutions because political prices have to be paid if they are to be adopted. A problem whose solution requires a great number of people to change their mindsets and behaviour is likely to be a wicked problem. Many examples come from the areas of public planning and policy. These include global climate change, natural hazards, healthcare, the AIDS epidemic, pandemic influenza, international drug trafficking, homeland security, nuclear weapons, and nuclear energy and waste. Food production and trade and food policy generally are wicked problems.

tiny farms which have vast collective impacts on water resources and frequently on the water services of the water environment through the way they manage water and land. Perhaps a billion of the three billion souls that depend on farming are in families dependent on subsistence farming. They do not participate in markets at all. Many of the farmers who are part of a market system have no or very little market power. By contrast in advanced economies farmers can play a pivotal role in the workings of the local market and of the global market. Often after decades of deeply embedded subsidised operation, they have significant influence on the allocative politics of their respective national economies. They can even be huge corporations with clear interests. The farm lobby which is as old as farming, and those lodged in the systems of Washington and Brussels, influence global markets.

The point being made is that private sector players manage and mismanage the 90 per cent of water used by society. This is the water in the food supply chain. All international trade in food commodities is also in the private sector – albeit in a trading regime influenced by the farmer pressured governments of some major national economies. All the consumption decisions are made by individuals in society – accessing options enabled by the private sector. And almost all of the processing and delivery of wholesale and retail services of food commodities is in the private sector (Allan, 2010).

The water-food-trade-consumption nexus in the food supply chain

Awareness of the water-food-trade-consumption nexus has experienced a number of phases. In the 1990s only the water food and trade elements were considered. First, it was shown that the nexus had powerful explanatory power in explaining the absence of armed conflict over shared transboundary waters (Allan, 2001). By 2000 Hoekstra et al produced a first approximation of global virtual water 'trade' and much detail on the virtual water 'imports' and 'exports' of about 130 economies. By 2004 the same group published the water footprints of these economies and of a number of key agricultural commodities. All of this research was carried out by university scientists who have contributed chapters to these proceedings.

The next and very recent phase of research and revelation – since about 2007 - has been the result of the message about embedded water reaching major private sector players – in agribusiness, in commodity processing and trading and in food retailing. Major corporations such as Unilever, Nestlé, Coca-Cola, Pepsi, SAB-Miller and a large number of super-markets such as Walmart and Tesco are now engaged. We are in the middle of a rapid take-off and evolution of this paradigm.

The difference between these corporate agents and farmers is that these private entities have a brand reputation to protect and all engage very intimately with consumers who are their customers. As a consequence they are very reputational risk aware and observe closely the shifts in the beliefs and preferences of customers. The beliefs and preferences of consumers in OECD economies are at the same time subject to contradictory driving forces nurtured by the brand corporates. In this process many consumers have become addicted to diets that will bring them ill-health including diabetes and impose terrible additional consequences on the water environment.

Other consumers want to point society and the corporates in the opposite direction informing them of metrics on water and energy footprints of unhealthy eating. It is proving to be an exciting and sometimes volatile discourse.

Who owns, does, controls and gets what?

Figure 2.3 summarises who owns, does, controls and gets what in the water-food-trade-consumption nexus that operationalizes the food supply chain. The diagram provides columns that indicate who is owning, doing, controlling and getting what - first within the food producing farming sector, secondly in the food commodity trading sector, and thirdly in food consumption. Within each of the three major phases of the supply chain there are six columns. The first four enable the influence of the *four social solidarities* that are involved in organising society to be analysed. That is by the engagement of *civil society*, the *public sector* (.gov), the *private sector* (.com) and the *civil movements and NGOs* (.org). Two additional columns are shown to capture first, where the *WTO* is having influence and secondly, where a voice is present to advance the protection of *water's environmental services*. If the book had been about the protection of employment rights rather than the protection of water services we would have found that the WTO has been looking at labour and employment issues for much longer than at environmental issues.

The key players in the international political economy that underpin global and local water security are not obvious. Though often invisible these players do exist in civil society, in government, in the private sector and in civil movements. Sometimes they are visible but not very determining of outcomes. The WTO, for example, is a rule making body that does not have universal reach. It has had great difficulties in establishing fair terms of global trade for the weak economies of the world. Activist voices speaking for the protection of natural resources and for the environmental services of water have become prominent but they have as yet had limited influence on trade in the food supply chain. They engage in three main sequential activities - in *agricultural production*, in *agribusiness and food processing* and in *food consumption*. The ethical activists are eternally disappointed that their impacts are limited but there is evidence that they are having significant impacts during the period that this book is being written and published (National Jesuit Committee on Investment Responsibility, 2010; Bunge, 2011).

Who owns and does what?

The ownership of land necessary for food production, and of the water associated with that land, is clearly positioned in civil society and the market. Where water is a public good or a common pool resource it is accessible to billions of farmers in civil society. They use relatively small volumes of water compared with the volumes used by corporate farmers. These forms of ownership vest in farmers the destiny of water use and misuse.

The global trade in food commodities is owned and controlled by the market and mainly by a small number of corporations based in OECD countries. This single sentence captures the power relations of international global food commodity trade.

Figure 2.3. A preliminary analytical framework highlighting some key features of the water and food production, trade and consumption nexus. The purpose is to highlight owns the asset or the activity, who does things in managing it, who controls or seeks to control it, and whose behaviour impacts and who benefits or dis-benefits? The three major elements or stage in the supply are shown in the vertical structure – production, trade and consumption. The analysis reveals that private sector agents are prime at all stages. Civil society is important with respect to ownership and extremely important with respect to consumption. The state and other public agents play minor roles and international public agents such as the WTO is not yet significant.

	Total global production						**Strategic global Trade**						**Consumption**					
	Farmers												In OECD economies 30% is bad for health & the environment & 30% wasted. In developing economies 30% is wasted.					
	100% of all production						**c15%** of all food produced											
	CS	.Gov	.Com	.Org	Evt	WTO	CS	.Gov	.Com	.Org	Evt	WTO	CS	.Gov	.Com	.Org	Evt	WTO
Owns	OO OO						.						OO O					
[Own-		O						.						O				
ship & control of			OO O						OO OO						OO O			
assets]				.						.						.		
					.	.					.	.					.	.
Does	OO OO						.						OO OO					
[Labour and		O	OO OO					O						O				
manage-ment				.					OO OO						OO OO			
inputs]					.	.				.						.		
											.	.					.	.
Controls	OO						.						OO OO					
[Power		O						O						O				
over production,			OO						OO OO						OO O			
trade &				.						o						o		
consumption]					X	.					.	?					.	.
Gets	OO						.						OO OO					
[Benefits		o						O						O				
and disbenefits]			OO O						OO O						OO O			
				.						.						.		
					XX	.					X	.					XX	.

CS Civil Society **Gov** Public sector **Com** Market/Private Sector **Org** NGOs & Civil Movements
Env Environment voice **WTO** World Trade Organisation

[.] Not relevant or unmeasurable [?] In progress
O Low, OO Mid, OOO, High, Very High X Negative, XX Very Negative,

The analytical framework does not work so well for the notion of ownership with respect to consumption. The consumer can be inspired by diverse economically and environmentally rational underlying fundamentals leading them to value water and to be aware of the environmental sustainability of their consumption. They may even be aware of their evolved or manipulated preferences. Even of their dangerous addictions. These psychological conditions determine what consumers decide and do. They also determine whether they exert control as well as whether they achieve the benefits of healthy well-being or damage their health and at the same time ruin the water and other natural environments. The socio-political processes that reinforce and change behaviour are clearly so important that they deserve close attention by everyone deeply involved in the food supply chain. The incentives to move consumers and food suppliers to avoid being involved in trading and consumption process that cause negative impacts are not yet much in place. But the discursive processes (Sojamo, 2010) are gathering pace amongst activist movements such as Slow Food (2011) and its Terra Madre Day and its Food Day activities world-wide. The ethical investing movements are also becoming influential (National Jesuit Committee on Investment Responsibility, 2010).

In brief, it is evident that civil society and the market are the dominant players with respect to the ownership of water. What they believe about water, what they know about it and what they do not know are very significant indeed. The farmers, traders and consumers are linked by markets. None of them are aware of the volumes of water in the supply chain. Most of them are unaware of the concepts of water productivity, of the significance of green water dependent crop yields, and of water footprints. Only the brand corporations have begun to take an interest. The main food commodity traders – the non-brand corporations – are unaware of their role in handling the virtual water in the commodities they trade (Conway, 2010), but they are adapting rapidly to the calls that they should engage.

Because ownership is so empowering in the food supply chain the pattern of doing is almost identical to the pattern of owning. Farmers – operating at all scales - are the biggest owners of water. They therefore have the capacity to do more – well or badly -with water than any other agents. What civil society and the market decide determines how water is used. Farmers in civil society particularly determine whether the use of water is sustainably intensified or not. Poor farmers have few options. Big commercial and corporate farmers have more potential options. The consumption decisions of consumers are clearly determined by a manipulated civil society and to some extent by the decision making of private sector enterprises who provide food services. Both these types of decision maker are as yet poorly informed but still pivotal as they have such potential impacts on the health of society and of the water environment. The food consumption decisions of an increasingly diverse and rich world are hard to estimate but they are of unavoidable massive and increasing significance.

Who controls what?

Water resource allocation and management in the very water intensive food supply chain is in the hands of farmers, commodity traders and consumers all of whom are subject to market forces. The overwhelming sway of market processes is feared by those whose livelihoods depend on growing and selling food at the beginning of the supply chain. Drought and flood are also feared. Farming has been an uncertain livelihood since Neolithic farming took off 13000 years ago. The farm lobby has politicised food production since the dawn of civilisation. The politicisation has recently become more intense. There has been the need first, to improve crop productivity and more recently to grapple with the challenge of delivering sustainable intensification requiring the stewardship of the environment.

Those who would control the way farmers manage their inputs have limited tools at their disposal. Water for crop production is not widely valued in crop production. The state may have invested heavily in irrigation infrastructure. But farmers are unwilling to pay for the water and generally win the battles against those who want there to be a price for water that reflects its investment and operational costs as well as environmental values. Green water is virtually a free good. Blue water is scarcely anywhere priced at even a fraction of its cost of delivery never mind at a price that reflects its value as an environmental service.

Society is only at the beginning of the regulatory journey to get its farmers to recognise the value of the 80-90 per cent of all water – green and blue - which they use on behalf of society to produce its food. Almost all farmers are blind to the volumes of water involved in food production. Most of them are also blind to the significance of the increases in water productivity associated with increased yields. That they prefer to devote the blue water saved by increased yields to the irrigation of additional areas shows that they do not yet value the environmental services of water. At this early stage of the regulatory journey we cannot get the market to generate the price signals that reflect the values of water. At the same time the perceived political prices of introducing radical regulation are much too high.

The volumes of the water embedded in food commodity trade have only very recently come to the attention of those who trade food commodities (Allan, 2011). The non-brand ABCD corporations and similar smaller corporations that handle most of the international food commodity trade have at the time of writing adopted the ideas in currency on climate change and energy footprints and other corporate responsibility mantras. But they are just becoming aware of their unique and very significant role in ‘moving’ the embedded water in the global water-food-trade nexus which they alone handle in their global operations (Conway, 2010). These corporations operate in a potentially very influential position in the supply chain. The brand corporations have begun to transmit messages to farmers who supply them about a range of natural resource and human rights issues which have been drawn to their attention by customers and NGOs. The potential of the food commodity traders who handle most of the virtual water ‘embedded’ in the supply chain have immense potential to influence resource managing behaviour up the food chain but for the moment this potential influence is scarcely mobilised. This is partly because such mobilisation is very difficult as the values involved do not align with the way markets currently work. And partly because only the brand corporations have the reputational incentive to adopt the values of natural resource stewardship.

The WTO was established to regulate international trade to bring about the benefits of responsible trade. It has always found it difficult to establish rules for food commodity trade as the interests of farmers in industrialised countries have been steered by production and trade subsidies. The Uruguay Round and the Doha negotiations have foundered over agricultural commodity trade. Even when agreements are reached over extreme issues such as cotton and sugar the politically determined outcomes are far from comprehensive in providing solutions. They are unwillingly adopted and subject to serious non-compliance.

Food consumers who drive the demand for food and therefore of water, do this through their food choices and the extent to which they waste food. There are no formal controls on the way food preferences and food wasting behaviours are expressed. Poverty is a practical curb (Banerjee et al., 2011) and is therefore significant for the too numerous poor in the world. For the rich the family income devoted to food purchases have become progressively less significant and too many consumers in rich economies are dangerously afflicted by obesity and diabetes. Bad diets associated with cheap food have unwittingly promoted these afflictions. There are very serious downsides of the cheap food policies brought about by a dangerous alliance of the market and governments. The availability of cheap food for consumers blind to what determines environmental security – including water security which is so closely related to the food supply chain – is a serious downside. Human health and environmental health suffer.

This type of regulatory regime needed is not well addressed by the normal incentives and practices of neo-liberal states and their markets. For example the individual consumers and their children have been tempted into food addictions by the market. Neither the market nor elected governments are good at dealing with such addictions. The addicts *vote* - and just as important - they are *customers*. The only way to have an impact on the water footprint of an individual consumer or collectively on a society is to change consumption behaviour. But the challenge is that the values that need to be captured and known about are not reflected in the price of the product. More important it is extremely difficult to track the complex role of water in the long supply chain. The importance of water to the farmer at the far end of the supply chain grappling with the uncertainties of climate and the market is not a priority to a poor consumer that needs cheap food or to a rich consumer who can easily afford to over consume and waste. The principled and wise food consumers are as yet in a minority.

The WTO has taken on board the need to recognise environmental priorities such as climate change and carbon trading and is developing principles to frame the negotiations on such matters. These precedents will inform and underpin the debate on how to recognise and then reflect the value of water resources in the supply chain. These issues are the focus of other chapters in these proceedings and so they will not be discussed here. These other chapters analyse the footprints of food production, trade, commodity processing and transportation as well as the extent to which these footprints can be taken into account in trade. For the moment this is the stuff of metaphor and advocacy. It is not yet the basis of regulated trade based on embedded water metrics that value the environmental services of water or the achievement of global water security

Who gets what?

The analysis so far has identified the winners and the losers in the *status qu*o food supply chain. *Farmers* in rich countries do not have an easy life. But in facing the challenges in the past half century they have massively increased the productivity of water - especially of green water. Farmers in the rapidly developing BRICs economies have also achieved massive increases in production and water productivity. There are further increases in water productivity to be achieved. Farmers everywhere have uncertain livelihoods and will have to be provided with significant price incentives if they are to respond to the global demand for food and at the same time become better stewards of the water environment.

The international non-brand ABCD food commodity *trading corporations* demonstrate what can be achieved in a very uncertain world in private sector, populated by a small number of mainly family firms, that give priority to understanding farmers and farming, as well as the national and international politics of farming and farm subsidies. These corporations have for 150 years honed their operations in trading, hedging, insuring, banking and more recently in trading other commodities such as oil and coal. They prove the importance of being supreme in market intelligence in a strategic market and the returns to be made from professional expertise and vigilance. The outcome has been a remarkable and sustained global presence and very high volume and value of trade. This is what these major players in the water intensive global food supply get from participation. Just one of these companies has an annual revenue of over US$ 100 billion and the others each have revenues of over US $50 billion. Four of them together have revenues in excess of the total GDPs of 60 countries that occupy the lowest places in the global league of national GDP. The revenues of these four corporations are equivalent to one third of the GDP of sub-Saharan Africa. Their chief finance officers point out that they deliver extraordinary value in that the [profit] margins are very thin after carrying the costs of futures, derivatives and bond markets in an strategically important, volatile and high risk global system. One per cent is usual. Two per cent exceptional.

What do the consumers get? They get food security and under-priced food commodities. The under-pricing is partly a consequence of the non-inclusion of all the costs and impacts of water; a condition that is unsustainable in the long run. But a proportion of the food that is cheap is also unhealthy. The addiction to cheap food is proving very hard to remedy. The expectation that food will get cheaper or at least remain cheap is a fundamental axiom of the food supply chain. Consumers expect it and governments and corporations are locked into meeting theses expectations. “Every little helps” as the advertising jingle goes. The food price rises linked to the energy price spikes of 2008 and 2010-2011 make governments quake. Some are arguing that they have triggered the Arab spring of 2011 with long-standing regimes tumbling (Harrigan, 2011). A quest to increase food prices to reflect the priorities of sustainable intensification and human health are promising messages for the principled organic food activist. The message is sound. But the message frightens politicians. Credit should go to the brand corporations that are attempting to get these messages passed back along the food supply chain. Consumers will need to be persuaded that the ways things they have gained via the global food supply chain in the past century need to be re-evaluated and changed.

That the brand corporations such as Nestlé, Unilever, Coca-Cola, Pepsi, Walmart and SABMiller are pointing in a principled direction confirms that the prominent gurus of neo-liberal capitalism such as Harvard based Michael Porter are laggards. He grudgingly recognises that the environmental activists have been providing the correct moral compass. And gives credit to the 30% of young people who come to Harvard with mindsets that have changed the discourse on the role of business in bringing about social and environmental equity in the seminar room and subsequently in the faculty club. Somehow he concludes that the mighty corporations in the capitalist market alone have the skills and capacities to implement a new version of capitalism that marshals consideration for the environment as well as the bottom line (Porter and Kramer, 2010). As has been argued we need above all expertise on market processes and on the conditions shaped by markets. All of the water intensive food supply chain is wholly enabled by the market with some useful and some distorting tweeks from governments. We need non-distorting tweeks from properly founded price signals and comprehensive and widely agreed WTO regulation.

For the moment three elephants are unaware they are in the room

> It is usual to be unaware of the elephant in the room but it is unusual to being unaware of being the elephant.

In tracking water in the food supply chain we have encountered a number of elephants in the global system in which food is raised, marketed, processed, internationally traded, retailed and consumed. Only the brand corporates and the supermarkets are coming to terms with their role in handling water in the long international food supply chain (Segal, 2009; WWF et al., 2009). All the others are unaware of being an elephant.

The first unaware elephant are farmers. They are for the most part unaware of the value of green and blue water and of the need to be good stewards of water as well as being more efficient water users. Farming livelihoods are very highly politicised. But the priority of securing the environmental services of water resources have no, or very little, leverage in these politics.

The second non-aware elephant is the solidarity of the non-brand food commodity traders. They are very rapidly becoming aware of their role in virtual water ‘trade’. But they are understandably reluctant to engage with the issue as water is not valued by anyone in the supply chain and there are no signs that price signals will be installed to make a market mediated process relevant or operational. Until now the non-brand global food commodity traders have protected their low profile existence in global food commodity trade. In this mode they cannot play a role in transmitting sustainable intensification messages from consumers and NGOs. One senses that these corporations are embracing these issues as readily as they adopted carbon trading. These firms do generate a significant energy footprint and are handling commodities with significant embedded energy. But until very recently they have been unaware of their elemental role in global virtual water ‘trade’. If these food trading corporations could devote as much skill and capacity to conveying the messages of sustainable intensification to the framers and government departments as they do to hedging against the uncertainties intrinsic to global commodity trade they could play a pivotal role in sustainable intensification and the stewardship of water.

The unaware third elephant is the solidarity of the food consumers. Like farmers they have a highly politicised position in the political economy of the food supply chain. They are feared by political elites and needed by those who supply food commodities in the food supply chain. Consumers in the OECD economies – both rich and poor - have become addicted to cheap food. Consumers in developing countries need cheap food. But the low food prices that prevail do not reflect the cost of the water inputs nor of the environmental costs of both industrialised food production and trading systems and of the inefficient operations in developing countries. The consumer is a very dangerous unaware elephant.

Policy relevance for those wanting to introduce consideration of sustainable intensification in food production, fair trading of food commodities and the sustainable consumption of food

> Food commodity trade has delivered food and water security but it does not deliver social and environmental justice. Markets are not designed to deliver them.

The water-food-trade-consumption nexus has worked many private sector miracles in the past two centuries. It has been especially effective in the past half century in enabling a trebled global population meet the water consumption needs that are integral to food consumption.

The outcome has had its downsides. Those currently engaged in the nexus in the food production, trading and consumption nexus which remedies the mal-distribution of water endowments are encountering problems of both *unsustainable intensification* and *unsustainable consumption*.

International trade links these two society induced problems. Food commodity trade has delivered food and water security but it does not deliver social and environmental justice. Markets are not designed to deliver them as they do not yet internalise the environmental costs of producing food commodities. Nor do they internalise the costs of polluting the environment or those of the ill-health consequent on addictions to unhealthy cheap food.

But if sustainable intensification and sustainable consumption are to be addressed then the private sector is overwhelmingly in a position to make a contribution as the whole long food supply chain is in the private sector. So far the corporations that have brands and reputations to defend have been taking initiatives that are directed by a newly found moral compass. However, the non-brands – the major players, who handle most by volume of production as well as by the volume of embedded water – are currently not playing a major role.

The brand corporations are getting themselves informed and are selectively sending messages to suppliers in their supply chains. The non-brands are just turning to give the issue some attention. They are playing a low profile role not much higher than the invisibility of the past century and a half century. They are not signalling the value of the environmental services of water. Nor are they highlighting the significance of diet and food waste in bringing about the sustainable management of scarce water resources. The farmers and consumers who have the solutions to water security in their water managing and virtual water 'consuming' practices are dangerously blind to the environmental and economic consequences of their ways of life. With such impediments to the communication of the need for the sustainable intensification of food production it will take as long to end the devastation of our water resources as it did to end the market in exploited people in the private sector markets and societies of two centuries ago. Markets do not naturally evolve safe moral compasses. They frequently have to be frightened into adopting them. We need to identify the fright that will mobilise the politics that will get farmers and consumers to know why water must be valued.

References

Aldaya, M.M., Allan, J.A. and Hoekstra, A.Y. (2010) Strategic importance of green water in international crop trade, *Ecological Economics*, 69(4): 887-894.

Allan, J. A. (2001) *The Middle East water question: hydropolitics and the global economy*, London: I B Tauris.

Allan, J. A. (2003) *Virtual water - the water, food, and trade nexus: useful concept or misleading metaphor? Water International*, 28(1): 106-113.

Allan, J. A. (2010) Prioritising the processes beyond the water sector that will secure water for society - farmers in political, economic, and social contexts and fair international trade, in Martinez-Cortina, L., Garrido, A., and Elena Lopez-Gunn, E., *Re-Thinking Water and Food Security*, Fourth Marcelino Botin Foundation Water Workshop - Hardcover (30 Sep 2010), Leiden & Oxford: CRC Press and Taylor & Francis.

Allan, J. A. (2011) *Virtual water: tackling the threat to our planet's most precious resource,* London: I B Tauris.

Banerjee, A. and Duflo, E. (2011) More than 1 billion people are hungry in the world, But what if the experts are wrong? *Foreign Policy,* May 2011.

Beck, U. (1999) What is a 'risk society'? *Prometheus*, Vol 1.1, Winter 199, pp 75-79.

Bunge (2011) personal communication.

Chambers, A., and Trengove, G. (2009) *The implications of information asymmetry for the achievement of Australia's national water objectives*. A contributed paper presented to the 53rd annual conference of the Australian Agricultural and Resource Economics Society Cairns, 11th - 13th February 2009.

Conway. P. (2010) Food security versus food self-sufficiency, in OECD, FAO, IAEA, IFPRI, Paris: OECD

Conklin, J. (2005) *Dialogue mapping: building shared understanding of wicked problems,* Wiley.

De Fraiture, C., Cai, X., Amarasinghe, U. A., Rosegrant, M. and Molden, D. (2004) Does international cereal trade save water? The impact of virtual water trade on global water use. *Comprehensive Assessment of Water Management in Agriculture Research* Report, 4. International Water Management Institute, Colombo: IWMI Working Papers, 48 p.

Frontier Economics Network (2008) The concept of 'virtual water' — a critical review. A Report Prepared for the Victorian Department of Primary Industries. Melbourne: Victorian Department of Primary Industries.

Giddens, A. (1990) *The consequences of modernity*, Cambridge: Polity Press.

Goleman, D. (1997) *Vital lies, simple truths*, London: Bloomsbury.

Grove, N. and Picot, A. (2010) Regulating virtual water flows: introducing an integrated political economy for virtual water trade, *Research Paper*, Institute for Information, Organization and Management, Munich School of Management.

Hajer, M. (1995) *The politics of environmental discourse: ecological modernization and the policy process,* Oxford: Oxford University Press.

Hoekman, B., Ng, F. and Olarreaga, M. (2006) Reducing agricultural tariffs or domestic support: which is more important for developing countries? in McCalla, A. F. and Nash, J., 2006, *Reforming agricultural trade for developing countries, Volume 2, Quantifying the impact of multilateral trade reform*, Washington: World Bank. pp 40-79. http://siteresources.worldbank.org/INTARD/Resources/ReformingAgTradeVolume2.pdf.

Harrigan J. (2011) *Did food prices trigger the Arab Spring*, Inaugural Lecture at SOAS, April 2011.

Lang, T., Barling, D. and Caraher, M. (2009) *Food Policy.* Oxford: Oxford University Press.

Le Vernoy, A. (2010) Agriculture and virtual water, in: *2020 European agriculture: challenges and policies.* Edited by Boulanger, P. H., and Messerlin, P. A.. The German Marshall Fund of the United States, Economic Policy Paper Series 10. pp. 32-36

Lundqvist, J. (2010) Producing more or wasting less? Bracing the food security challenge of unpredictable rainfall, in Martinez-Cortina, L., Garrido, A., Elena Lopez-Gunn, E,. *Re-Thinking Water and Food Security*: Fourth Santander: Botin Foundation

Lundqvist, J., de Fraiture, C., Molden, D., Berndes, G., Falkenmark, M., Holmén, H., Karlberg, L. and Lannerstad, M. (2008) *Saving water: from field to fork. Curbing losses and wastage in the food chain*. SIWI Policy Brief. SIWI, Stockholm, Sweden. www.siwi.org.

McCalla, A. F. and Nash, J. (2006) Reforming agricultural trade for developing countries, Volume 1, Key issues for a pro-development outcome of the Doha round, Washington: World Bank. http://siteresources.worldbank.org/INTARD/Resources/ReformingAgTradeVolume1.pdf

McCalla, A. F. and Nash, J. (2006) Reforming agricultural trade for developing countries, Volume 2, Quantifying the impact of multilateral trade reform, Washington: World Bank. http://siteresources.worldbank.org/INTARD/Resources/ReformingAgTradeVolume2.pdf

National Jesuit Committee on Investment Responsibility (2010) *Annual Report, Washington DC:* National Jesuit Committee on Investment Responsibility Jesuit Conference,

Porter, M. E. and Kramer, M. R. (2010) The big idea: creating shared value, *Harvard Business Review*.

Quested, T. and Johnson, H. (2009*) Household food and drink waste in the UK,* London: WRAP. www.wrap.org.uk/downloads/Household_food_and_drink_waste_in_the_UK_-_report.0157bbc8.8048.pdf

Rabo Finance India (2007) *How much food does India waste?* Report for the Government of India, Delhi.

Rittel, H. R. and Webber, M. (1973) Dilemmas in a general theory of planning," *Policy Sciences,* Vol. 4, Elsevier Scientific Publishing Company, Inc., Amsterdam, pp. 155–169. [Reprinted in Cross, N. (ed.), *Developments in design methodology*, J. Wiley & Sons, Chichester, 1984, pp. 135–144.], www.uctc.net/mwebber/Rittel+Webber+Dilemmas+General_Theory_of_Planning.pdf

Sauer, P., Dvorak, A., Lisa, A. and Fiala, P. (2003) A procedure for negotiating pollution reduction under information asymmetry: surface water quality case. *Environmental and Resource Economics* 24(2): 103-119.

Segal, R. and MacMillan, T. (2009) *Water labels on food: issues and recommendations*. London: Food Ethics Council, UK. 15 p.

Simms, A., Johnson, V. and Chowla, P. (2010) *Growth isn't possible. Why we need a new economic direction.* London: The New Economics Foundation

Slow Food (2011) www. slowfood.org

Sojamo, S. (2010) '*Merchants' of virtual water: the "ABCD" of agribusiness TNCs and global water security,* unpublished MSc dissertation, Department of Geography, King's College London.

Water Footprint Network (2011) www.waterfootprint.org

Waterwise (2007) *Hidden waters: we consume a lot more water than we can even imagine, and our water footprints extend far beyond our own nation's boundary,* London: Waterwise.

Weiss, T. (2007) The global food economy: the battle for the future of farming, London: Zed Books.

Wichelns, D. (2010) Virtual water: a helpful perspective, but not a sufficient policy criterion. *Water Resources*

Management, 24(10): 2203-2219.

Woodward, D. and Simms, A. (2006) *Growth isn't working. The unbalanced distribution of benefits and costs from economic growth*. London: The New Economics Foundation.

WRAP (Waste Resources and Action Programme) (2009) *Household food and drink waste in the UK*, London: WRAP. www.wrap.org.uk/retail/case_studies_research/report_household.html.

WWF and SAB Miller (2009) *Water footprints: identifying and addressing water risks in the value chain*, Leatherhead: WWF & SAB Miller.

3. Failure of the virtual water argument [5]

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Abstract
The virtual water concept and argument have been used to analyse the linkage between trade, food security, and water resources. The concept comes from the idea that water should be treated as a production factor and virtual water is the volume of water needed to produce a commodity or service. The virtual water argument then states that the importation of agricultural products that need important amounts of water represents the importation of water into a water-scarce country. The objective of this paper is to assess the virtual water argument and to present some possible explanations why its theoretical underpinning does not necessarily hold in all cases. The paper suggests that the main reason for the failure of the argument resides in the strong assumption of price equalisation, as well as other factors that distort investment patterns such as government programs and subsidies. Using Mexico as a case study, the paper shows that the water price equalisation hypothesis does not hold true, and that various factors, such as the level of agricultural trade liberalisation, influence virtual water flows rather than water endowments. Trade liberalisation via the North American Free Trade Agreement (NAFTA) significantly influenced the level of virtual water flows between Mexico and the United States.

Introduction

The virtual water concept and argument have been used to analyse the linkage between trade, food security, and water resources. The concept comes from the idea that water should be treated as a production factor and virtual water is the volume of water needed to produce a commodity or service. The virtual water argument then states that the importation of agricultural products that need important amounts of water represents the importation of water into a water-scarce country (Allan, 1996). Food trade then becomes an instrument to augment water supplies on the scale needed to meet the domestic food demand.

The factors embedded in trade or the factor-content approach was first employed by Leontief (1953) in his well-known test of the Heckscher-Ohlin (H-O) theorem. The H-O theorem posits that the pattern of trade between countries will be based on the characteristics of the countries. That is, countries will produce and export goods that use the factors of production with which they are well endowed. For example, the H-O theorem predicts that capital-abundant countries will create and export capital-intensive goods while labour-abundant countries will export labour-intensive goods.

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[5] Based on J. Ramirez-Vallejo and P. Rogers (2010) Failure of the Virtual Water Argument: Possible Explanations Using the Case Study of Mexico and NAFTA, Chapter 6 in *Global Change: Impacts on Water and Food Security*, C. Ringler, A. K. Biswas, and S. A. Cline (eds.), Berlin: Springer-Verlag, pp. 113–126.

Without trade, each nation would produce goods for their own consumption and the price of the capital-intensive good in the capital-abundant country would be low due to over-supply relative to the price of that good in a labour-surplus country. Similarly, in the labour-abundant country the price of the labour-intensive good would be bid down relative to the price of that good in the capital-abundant country. Thus, trade allows profit-seeking firms to move their products to the markets that temporarily have the higher price and trade flows will rise until the price of both goods are equalised in the two markets. It follows that free trade also tends to equalise relative factor prices across national borders (the factor price equalisation theorem). The H-O theorem, therefore, demonstrates that differences in resource endowments are one driver of international trade. The traditional implication of the H-O theory is that water abundance determines which agricultural commodities are exported and which are imported, in other words, the sign of net exports. Thus, the water content of trade can be used as an indirect measure of water abundance and the sign of the net trade in factor service, corrected for the trade imbalance, should reveal the abundance of water, compared with other resources on the average.

According to the theory, trade reveals the relative abundance of water resources when considering two countries at a time. That is, for each country, the ranking of adjusted net water exports should match the ranking of water by their abundance. This rank proposition is tested for each country by computing the Kendall rank correlation between corresponding rows of the vector of adjusted factor content and the vector of factor abundance ratios. Table 3.1 summarises the water content data by listing the ratio of the adjusted net trade in water to the national endowment of water in 2002, for each of 126 countries. According to these data, for example, Mexico imports 0.46% of the services of its water stock. During the same period the US exported 3.2% of the services of its water stock. In general, the proposition of conformity in sign between water endowment and excess water shares receives relatively little support. Moreover, using Fisher's Exact Test, the hypothesis of independence between the sign of the water contents and of the excess water shares cannot be rejected at the 95% level.[6] In addition, for only 44% of the countries did the sign of net trade in water match the sign of the corresponding factor abundance. Therefore, the water content of trade at the country level is not a measure of water abundance. Countries that have low levels of water resources do not necessarily import goods that demand significant amounts of water for production.

Possible explanations of the failure of the H-O theorem in virtual water using the case of Mexico

The main reason for the failure of the H-O theorem is that under conditions sufficient to guarantee factor price equalisation there exist many efficient production configurations in the world consistent with the equilibrium factor prices and a given distribution of factor endowments among countries. Therefore, it becomes hard to predict the indirect movement of a particular factor when there are more than two factors.

[6] Formal tests of the adjusted net factor export data with the factor abundance data including Fisher's Exact Test and the Kendall rank correlation are reported in Table 6.2 of Ramirez-Vallejo and Rogers (2010), p.118.

Table 3.1. Ratio of adjusted net trade in water to national endowment of water in 2002. Source: Ramirez-Vallejo and Rogers (2004).

Country	Ratio	Country	Ratio	Country	Ratio
Albania	0.34	Finland	0.40	Norway	0.22
Algeria	11.27	France	–2.24	Pakistan	0.14
Angola	0.20	Gabon	0.05	Panama	0.05
Argentina	–0.79	Gambia, The	0.40	Papua New Guinea	0.00
Armenia	0.68	Georgia	0.04	Paraguay	0.00
Azerbaijan	0.27	Germany	3.43	Peru	0.01
Bangladesh	0.06	Ghana	–0.12	Philippines	0.14
Barbados	62.61	Guatemala	–0.17	Poland	0.34
Belarus	0.29	Guinea	0.04	Portugal	1.62
Belgium	–5.39	Guyana	–0.02	Romania	0.17
Belize	–0.13	Haiti	1.35	Russian Federation	0.09
Benin	–0.09	Honduras	0.00	Rwanda	0.12
Bolivia	–0.02	India	–0.04	Sao Tome and Principe	0.20
Bosnia & Herzegovina	0.95	Indonesia	–0.04	Senegal	0.58
Botswana	0.06	Iran, Islamic Rep.	0.51	Sierra Leone	0.03
Brazil	–0.09	Italy	1.28	Singapore	105.11
Bulgaria	–0.29	Jamaica	1.03	Slovak Republic	0.43
Burkina Faso	–0.02	Jordan	28.20	Slovenia	0.55
Burundi	0.02	Kazakhstan	–0.12	Spain	–1.62
Cambodia	0.02	Kenya	–0.19	Sri Lanka	–0.12
Cameroon	–0.05	Korea, Rep.	5.78	Sudan	0.04
Cape Verde	12.42	Kyrgyz Republic	–0.05	Suriname	0.02
Central African Republ.	0.00	Lao PDR	0.01	Swaziland	0.19
Chad	–0.08	Latvia	0.83	Syrian Arab Republic	–0.34
Chile	–0.14	Lebanon	9.49	Tajikistan	0.03
China	0.04	Lesotho	1.07	Tanzania	–0.03
Colombia	–0.02	Lithuania	0.18	Thailand	–0.67
Comoros	0.34	Macedonia, FYR	1.43	Togo	0.01
Congo, Rep.	0.01	Madagascar	0.00	Trinidad and Tobago	1.23
Costa Rica	–0.45	Malawi	–3.35	Tunisia	8.01
Cote d'Ivoire	0.29	Malaysia	–0.20	Turkey	–0.06
Croatia	0.40	Mali	–0.02	Turkmenistan	–0.03
Czech Republic	–9.76	Mauritania	0.96	Uganda	–0.08
Denmark	–39.22	Mauritius	–0.34	Ukraine	–0.60
Djibouti	25.20	Mexico	0.46	United Kingdom	4.98
Dominican Republic	0.69	Moldova	–1.18	Uruguay	–0.28
Ecuador	–0.13	Mongolia	0.08	Uzbekistan	–0.43
Egypt, Arab Rep.	1.99	Morocco	1.89	Venezuela, RB	0.06
El Salvador	0.84	Mozambique	0.05	Vietnam	–0.04
Estonia	1.20	Nepal	0.01	Yemen, Rep.	10.10
Ethiopia	–0.06	Niger	0.09	Zambia	0.04
Fiji	–0.08	Nigeria	0.31	Zimbabwe	–0.90

Numbers in per cent.

As Wichelns (2004) has pointed out, the virtual water argument addresses resource endowments, but does not address production technologies or opportunity costs. More specifically, the price equalisation hypothesis that underlies the H-O theorem rarely applies in the case of water as an agricultural input. The assumption is made in spite of the common knowledge that factor price equalisation is widely at odds with water price and agricultural data. Values of water differ significantly from one country to the next, and even within countries. Moreover, the price for water that is actually paid by farmers and that is internalised in the farmer's decision process is distant from the true opportunity cost of water.

The distortion of virtual water movement is also a consequence of the level of liberalisation of agricultural trade, as well as the domestic support to agriculture. Using the case of Mexico, Ramirez-Vallejo and Rogers (2010) show how the factor price equalisation hypothesis does not apply in the country, and that the liberalisation of agricultural trade and the agricultural support given to domestic producers have impacts on virtual water flows.

Virtual water and the price of water in Mexico

A farmer's choice whether to plant water-demanding crops does not depend on the level of water-scarcity. For instance, in the irrigation districts in northern Mexico, farmers continue to cultivate cereals and other water-demanding crops (high levels of virtual water) because of the highly subsidised crop prices and low water fees administered by the government. Without agricultural subsidies, the farmers in these districts probably would have switched from cereals to fruits and vegetables or to higher-value crops after NAFTA came into effect to take advantage of the opportunities presented by the US market.

The factor price equalisation hypothesis is widely at odds with the large variation in water prices in Mexico. Water prices vary significantly across irrigation districts in Mexico, and the economic value of water, as the maximum amount a user is willing to pay for using the resource, significantly varies among irrigation districts (Table 3.2). The shadow price, or willingness to pay for water, in the irrigation district of Río Mayo in the state of Sonora is a third of the shadow price of irrigation water in the San Juan del Río irrigation district in the state of Querétaro.

If the H-O theorem applied to water, then the virtual water concept would have to be consistent with the concept of opportunity cost of water use. Countries in which water is particularly scarce might benefit by importing water-intensive agricultural goods. In Mexico, water prices are below the opportunity cost of water. Moreover, in this country the opportunity cost of water is not considered when seeking an efficient allocation of scarce water resources. Therefore, the country would probably produce water-demanding goods above the optimal level, where the right mix of production and imports satisfies domestic demand. Water fees are a very small proportion of the opportunity cost of water in various irrigation districts in Mexico (Figure 3.1). This gap between the shadow price for water and the water fee has a strong influence in the farmer's choice of crops, mainly when water tariffs comprise a large portion of production costs.

For instance in Table 3.3, for the Spring-Summer cycle of corn and wheat using gravity irrigation technology, water fees amount to about 14% of the total production costs, and when the labour used specifically for irrigation is included, irrigation could amount to almost 20% of the cost (Ramirez-Vallejo and Rogers, 2004). This is roughly equivalent to the amounts required for fertilisers and for all other farm labour. Under these conditions water is surprisingly one of the major cost factors in agricultural production. However, in the Angostura irrigation district in Northern Mexico, the cost varies depending on the crop, the technology, the type and location of the irrigation district, and the crop cycle. It varies from 1% in high-value crops, such as grapes; to magnitudes even higher than 30% in low-value crops. On average for traditional crops, such as cereals, the amount lies between 7% and 12%.

Table 3.2. Estimated economic value of water for some irrigation districts in Mexico. Source: Ramirez-Vallejo and Rogers (2004).

Irrigation District	Shadow Price MEX$/m^3 1997–2001
001 Pabellón, Aguascalientes	1.568
005 Delicias, Chihuahua	0.929
010 Culiacán-Humaya, Sinaloa	1.557
011 Alto Río Lerma, Guanajuato	0.888
014 Río Colorado, Baja California & Sonora	1.552
017 Región Lagunera, Coahuila & Durango	2.050
023 San Juan del Río, Querétaro	2.000
024 Ciénega de Chapala, Michoacán	1.578
038 Río Mayo, Sonora	0.677
041 Río Yaqui, Sonora	0.907
075 Río Fuerte, Sinaloa	1.325
076 Valle del Carrizo, Sinaloa	1.737
92a Río Pánuco, Tamaulipas “Animas”	2.637
92b Río Pánuco Pujal coy, San Luis Potosí	1.329

1 Mexican peso ($) equalled US$0.10.

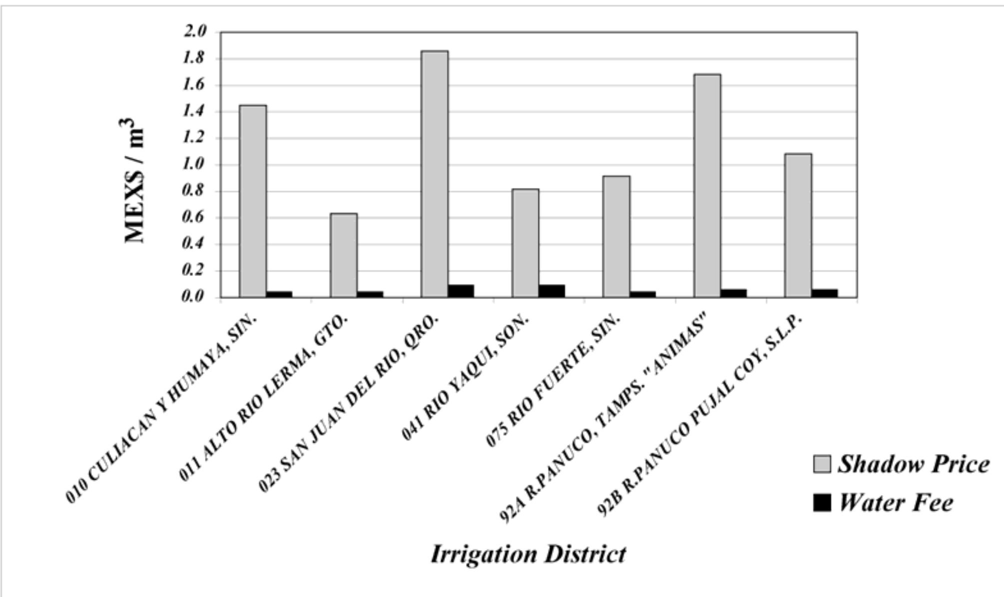


Figure 3.1. Comparison between shadow prices of water and water fees in various irrigation districts in México. Source: Ramirez-Vallejo and Rogers (2004).

Table 3.3. Share of O&M tariffs in total production cost, irrigation districts in northern Mexico – 2003. Source: Ramirez-Vallejo and Rogers (2004).

	Irrigation O&M tariff		
Crop	Gravity	Sprinkler	Drip
Fall-Winter Cycle			
Corn	9.7%	6.9%	4.4%
Wheat	12.4%	6.5%	5.7%
Safflower	12.9%	11.8%	6.7%
Beans	7.5%	4.3%	3.6%
Garbanzo beans	9.1%	4.8%	4.0%
Spring-Summer Cycle			
Corn	13.1%	7.0%	5.9%
Wheat	14.6%	8.5%	7.3%
Perennial			
Grapes	0.8%	0.0%	0.3%
Fodder	31.0%	15.9%	11.5%
Alfalfa	19.4%	10.0%	7.5%

Virtual water and trade liberalisation

The level of protection to agricultural products via tariffs and duties and non-tariff instruments by all countries, developed and developing, distorts the virtual water movement worldwide. Ramirez-Vallejo and Rogers (2004) have shown, for example, that using IFPRIs IMPACT model results, a scenario of full liberalisation of agriculture compared to a baseline scenario would generate a significant net effect on virtual water flows mainly from the relocation of animal products (meat) trade.

The North American Free Trade Agreement (NAFTA) transformed the structure of border protection for Mexico's agricultural sector. Mexico gained market access to the Canadian and the United States markets with two separate agreements signed with these two countries. Some products that Mexico considered as basic crops were liberalised. From the beginning of the agreement, sorghum, sesame, and sunflower seeds from Canada and the United States have entered free to Mexico. Free trade has also applied to seeds for cropping of barley, beans, maize, cotton, soy and sunflower, and since January of 1998, all types of soy have also entered free to Mexico from its two North American partners.

NAFTA produced significant shifts in virtual water flows mainly between Mexico and the United States. Domestic Mexican producers of importables were forced to compete with foreign goods (especially those coming from the United States) and therefore virtual water imports increased as a consequence of the reduction of tariff and non-tariff barriers. In addition, deregulation of the markets of these products led to falling product prices and, hence, to a reduction of their domestic virtual water supply.

Figure 3.2 shows "the virtual waterfall of NAFTA." NAFTA generated an increase in virtual water imports to Mexico of more than 100%. From an annual level of 20.4 Km^3 before the agreement, virtual water imports increased to a level of 43.5 Km^3 after NAFTA. This explains why, currently, Mexico is the second largest virtual water importer in the world after Japan with imports of more than 50 cubic kilometres per year, mostly coming from the United States (Ramirez-Vallejo and Rogers, 2004). Virtual water exports have also increased since the beginning of NAFTA. From an annual level of 1.14 Km^3 of virtual water going from Mexico to the United States at the beginning of the 1990s, virtual water exports expanded to 1.67 Km^3 at the end of the decade.

In terms of individual products, beef was the source of virtual water most affected by NAFTA. Virtual water imports to Mexico rose from 4% to 21% of total water used in domestic beef production from 1993 to 2001. This is explained by the high production costs and low product quality due to phytosanitary reasons that did not allow entry into the US market. On the other hand, virtual water from pork also increased significantly from 5.8% to 18% in the 1993–2001 period.

The above changes are explained by the diet adjustments of Mexicans as a result of the new commercial conditions created by NAFTA. During the 1990s the per capita consumption of beef went from 12.3 to 16.4 kilograms, and the per capita consumption of pork went from 11.2 to 14.1 kilograms. Per capita consumption of chicken increased by more than a factor of 2 in ten years; it went from 9.4 to 21.3 kilograms. Consumption of eggs went up from a level of 18.2 to 23 kilograms per capita (Yunez-Naude, 2002).

Virtual water exports from fruits and vegetables grew by 118% after NAFTA, mainly because Mexico has a competitive advantage in these products with respect to the United States and Canada due to its climate and the lower labour costs. However, in general, the cultivated areas in vegetables dropped while the yields increased significantly in the post-NAFTA period.

With regard to changes in crop composition before and after the Free Trade Agreement, there was no significant change in land use. In terms of cultivated area, the trend has remained the same both for importable and exportable products. The fact that production of corn under rain-fed conditions has not collapsed is one of the reasons why—counter to expectations—virtual water entering the country was not any larger than today's levels.

Beginning in 1995, the quotas for barley, beans and maize grew each year and their above-quota tariffs were subject to a yearly process of reductions. This process of liberalisation was designed under NAFTA for beans and maize to reach full free entrance to Mexico by December 2007. Full liberalisation for barley was faster: it was reached in January 2003.

The level of support or protection to agriculture is also significant in explaining virtual water demand. Elasticity for the support of agriculture was found to be –0.9 (Ramirez-Vallejo and Rogers, 2004). This relationship is evident when comparing the support to agriculture measured as Producer Subsidy Equivalent (PSE) and Net Trade of Virtual Water for various countries (Figure 3.3).

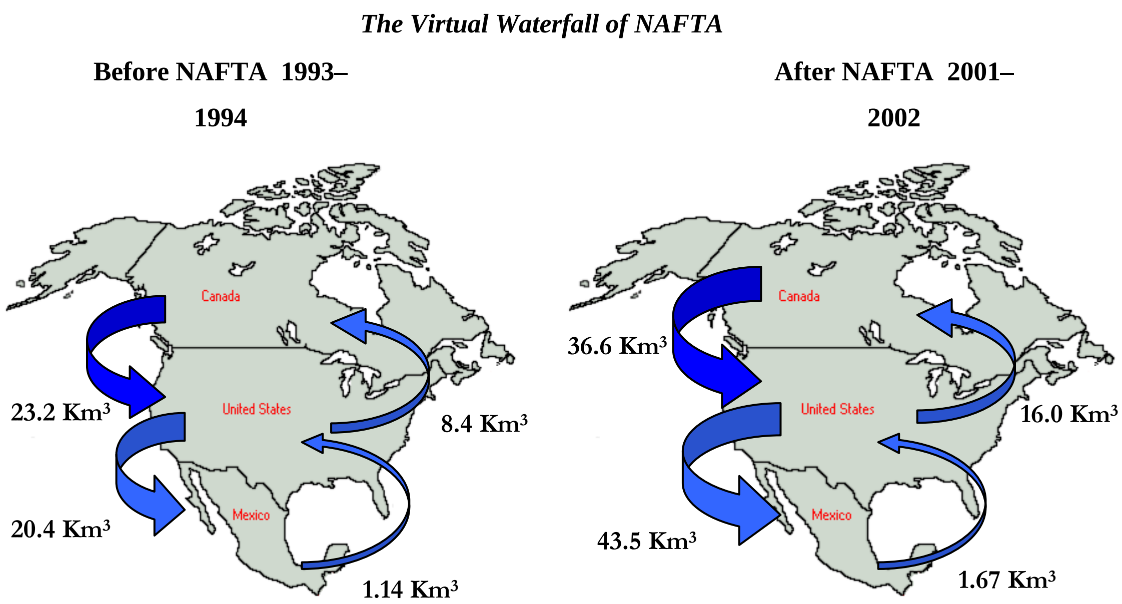
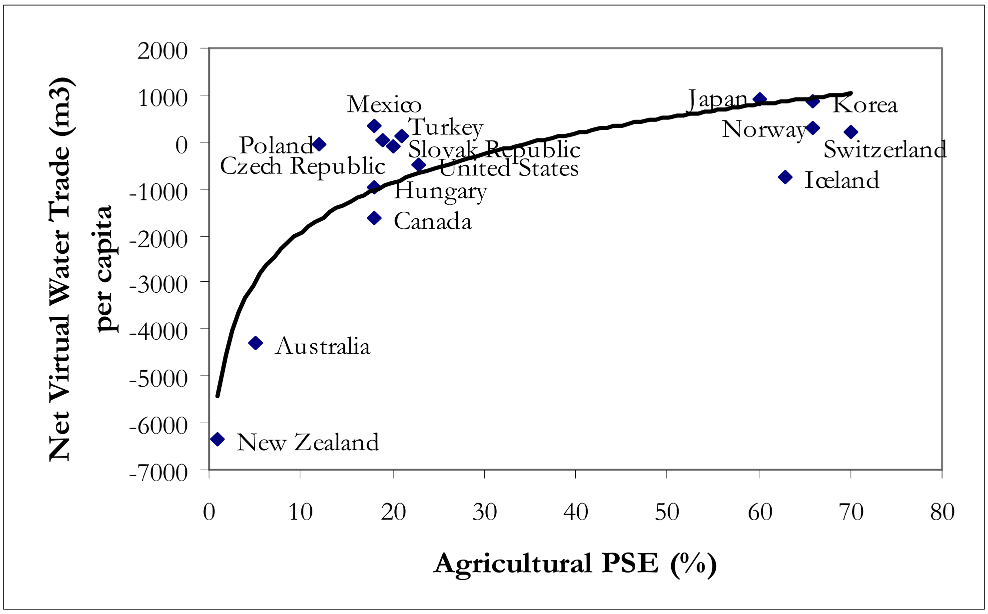


Figure 3.2. Trade in embodied water in agricultural products / livestock before and after NAFTA.



Note: The Producer Subsidy Equivalent (PSE) was developed by the OECD to measure agricultural support or assistance

Figure 3.3. Agricultural subsidies and net virtual water flows.

Other factors that influence the virtual water flow in Mexico

Besides income, virtual water is also influenced by governmental administrative procedures. The Mexican government, for instance, has followed four allocation mechanisms for TRQs (trade rated quota): direct assignment, auctions, government monopoly and "first come-first served." Maize and barley have been subject to direct allocations, and dry beans to auctions. Additionally, up to 1999, the Ministry of Agriculture defined the amount of the crop to be allocated to sustain the tortilla subsidy program. The rest of the maize quota was allocated to private cattle feeders (Shagam and Plunkett, 1997).

Virtual water could also be stopped at the border through many other trade instruments. Mexico, for instance, has included a safeguard clause for several agricultural products that, under NAFTA, can be used as a "countervailing mechanism" when an increase of imports represents a "considerable menace" or "serious damage" to the sector in question.

Trade policies are not alone in affecting virtual water flows. Domestic policies such as credit to agriculture influence the amount of this flow as well. In Mexico, credit subsidies and official credit coverage for working capital given to farmers by public financial institutions for rural development (the most important being BANRURAL) declined sharply during the nineties, due mainly to public budget restrictions leading to a very high default rate from the benefited farmers. Credit restriction may have limited the opportunities that liberalisation provided to farmers to change their production to competitive crops under NAFTA. Total credit granted to agriculture was 21% higher in 1983–90 with respect to 1996–2000.

Another key variable that drives virtual water flows is the evolution of the real exchange rate. In the case of Mexico, it has played an important role in explaining the unexpected trends of agriculture. The devaluation of 1995 helped farmers face competition from US producers of grains, and promoted the exports of Mexico of vegetables and fruits.

Conclusions

The virtual water argument shows that a water-scarce country uses imports of agricultural products as a way to import water to compensate for its scarce water endowment. The argument suggests the possibility that a water-short nation should try to save water by importing food from international markets. The argument implies then a direct relationship between imports of virtual water and the level of water endowment at the country level.

A formal test of the H-O theorem was performed and showed that the virtual water argument does not hold across countries. The reason for the failure of this theorem resides in the strong assumption of price equalisation, as well as other factors that distort trading patterns in the world such as government programs and subsidies.

In the case of Mexico, for example, trade liberalisation via NAFTA influenced significantly the level of virtual water flows. However, water prices are different in various parts of Mexico, and these prices are well below the opportunity cost of water. This situation, combined with the fact that water tariffs are in some cases a high proportion of production costs, has biased the choice farmers made to cultivate water-demanding crops.

The concept of virtual water is an appealing means toward educating public officials and society in general that water in some parts of the world is a scarce resource and that agriculture uses the great majority of water resources available on earth. The argument also offers an implicit lesson underscoring the importance of running irrigation districts efficiently so that water can be allocated to other uses including ones benefiting the environment. However, the virtual water argument, if applied improperly, can send the wrong message in terms of policy-making in agriculture and water resources. For instance, a country may delay important investments now, deciding instead to import food grains; or it could choose not to remove price subsidies with the objective of saving water.

References

Allan, J.A. (1996) Water use and development in arid regions: Environment, economic development and water resource politics and policy. Review of European Community and International Environmental Law 5, pp. 107–115.

Leontief, W.W. (1953) Domestic production and foreign trade: The American capital position re-examined. Proc. of the American Philosophical Soc., 97, pp. 332–349; reprinted in Caves, R.E. and Johnson, H.G. (Eds.) Readings in International Economics. London: Allen & Unwin, 1968.

Ramirez-Vallejo, J. and Rogers, P. (2004) Virtual water flows and trade liberalization. Water Science and Technology, 49, pp. 25–32.

Ramirez-Vallejo, J. and Rogers, P. (2010) Failure of the virtual water argument: Possible explanations using the case study of Mexico and NAFTA. Chapter 6 in Ringler, C., Biswas, A.K. and Cline, S.A. (Eds.) Global Change: Impacts on Water and Food Security, pp. 113–126. Berlin: Springer-Verlag.

Shagam, S. and Plunkett, D. (1997) Tariff rate quota administration in Mexico: 1994–97. Presented at the International Agricultural Trade Research Consortium, San Diego, CA: IATRC.

Wichelns, D. (2004) The policy relevance of virtual water can be enhanced by considering comparative advantages. Agricultural Water Management 66, pp. 49–63.

Yunez-Naude, A. (2002) Mexico's basic-crops subsector: Structure and competition under free trade. In Loyns, R.M.A., Meilke, K., Knutson, R.D. and Yunez-Naude, A. (Eds.) Structural Change as a Source of Trade Disputes Under NAFTA, Proceedings of the Seventh Agricultural and Food Policy Systems Information Workshop, 14–17 Feb. 2001. Winnipeg, Canada: Friesen Printers, pp. 308-322.

4. International farm trade in Latin America: Does it favour sustainable water use globally?

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Abstract

International agricultural trade has been growing significantly during the last decade. Many countries rely on imports to ensure adequate food supplies to the people. A few are becoming food baskets of the world. This process raises issues about the food security in depending countries and potentially unsustainable land and water use in exporting countries. In this paper, we ask whether farm trade can help the world to feed itself more sustainably. We analyse farm exports and imports of five Latin America countries (Brazil, Argentina, Mexico, Peru and Chile). A preliminary analysis indicates that virtual water imports can save valuable water resources in water-short countries, such as Mexico and Chile. Major exporting countries, including Brazil and Argentina, have become big exporters due to abundant natural resource endowments. The opportunity costs of agricultural production in those countries are identified as being low, because of the predominant green water use. It is concluded that virtual water trade can be a powerful tool to alleviate water stress in semi-arid countries. However, for exporting nations a sustainable water use can only be guaranteed if environmental production costs are fully reflected in the commodity prices. However, there is no basis for erecting environmental trade tariffs on exporters. Setting up legal foundations for them in full compliance with WTOs processes would be a daunting task. There is a need to evaluate the impact relationship of water scarcity and trade, and establish the causality.

Introduction

During the last few years particular attention has been paid to water resources availability as a limiting factor in agricultural production and thus the potential to feed the world (Affuso, 2010; Yang and Zehnder, 2002). Some countries already suffer water shortages resulting in food insecurity. This water crisis will likely be aggravated by climate change as well as an increasing demand due to a rapid demographic growth and dietary changes (Affuso, 2010; Liu et al. 2008; Liu and Savenije, 2008). However, this crisis is more a regional than a global problem, because of globally unevenly distributed water resources (Yang and Zehnder, 2002; Rockström et al. 2010). In a scenario of a globalised world, a possible solution capable to mitigate the water deficiency of different countries is the concept of virtual water trade (Allan, 1998; Falkenmark and Lannerstad, 2010).

Virtual water is defined as the water used to produce a commodity, good or service, that is traded internationally (Allan, 1998; Wichelns, 2004). The concept of virtual water trade defines one possible demand-side adaptation opportunity for water-short nations by purchasing a portion of its food requirements in international markets, rather than using scarce water resources to produce all food crops themselves (Wichelns, 2004).

Nevertheless, increasing trade between countries and continents also raises the question of sustainable water use in the world’s leading agricultural exporting countries. Water that is used for the production of water-intensive export commodities can no longer be used for other domestic purposes. Also, the social and environmental costs that are often associated with an excessive water use remain in the exporting countries.

This trend of an increasing reliance on farm trade and productive specialisation raises a number of crucial issues. First, the recent experience during the food crisis of 2007 and 2008 was a painful lesson to some of the poorest importing countries. Second, hotspots can be created in the exporting countries that do not have the capacity or the political willingness to curtail powerful exporting sectors on the basis of environmental constraints. Third, eating habits can change in favour of more standardised diets, against local culture and locally produced goods. And fourth, it goes against common sense and basic economics thinking that the world will ever feed itself sustainably and equitably without world champions of food production supplying the rest of the world commodities at the lowest cost.

Underlying some of these issues is the role of the World Trade Organisation, whether WTO's trade rules should include provisions and regulations meant to ensure that the negative environmental consequences of farm trade can be brought to the minimum. In other words, one can ask whether there is rationale for erecting trade barriers based on unsustainable resources conservation and management against exporting countries.

The aim of this paper is to illustrate the concept of virtual water trade and its potential but also risk factors for selected Latin American countries. The study considers international agricultural trade and its development over the last decade. The analysis of both perspectives, of major importing and major exporting nations, illustrates the role of international trade in achieving global food security in a sustainable manner. In light of this, we reflect on the WTO's role in, not only securing transparent and rules-based world trade, but also in helping sustainable water and land use.

Global food and water issues: the role of international farm trade

Per capita food production has increased dramatically in the last years in Vietnam, Brazil, Argentina, or India. It has not grown or even gone down in many African, Asian and Latin American countries. As of October 2010, 30 countries (21 African, 8 Asian and 1 Latin American) were catalogued as "countries in crisis requiring external assistance for food" by F.A.O.

F.A.O. claims there is still considerable the potential for increasing world food production. Yields are still very low in Africa, and have remained stagnated for the last 30 years. Even in some Latin American countries, Russia and Ukraine yields have risen less than in other world areas. CAWMA (2007) made preliminary assessments of the potential to expand irrigation areas in most continents. You *et al.* (2010) evaluated that there is economic potential for the expansion of irrigation in Africa for 16 million hectares. A similar study was made in 2000 for Latin America (Ringler *et al.,* 2000).

However, there will always be a mismatch between the areas with the largest potential and the populations living in countries without capacity to produce more. There is wide acceptance that a healthy, non-purely vegetarian diet (3000 kcal/day) requires 1,300 cubic meters per day. This is why Falkenmark and Lannerstad (2010) conclude that some countries will either need to rely extensively on virtual water trade or else live on quasi-vegetarian diets. They conclude that "... global food security with present dietary tendencies develops into a 1/3–2/3 world of massive food trade from water surplus countries to almost 5,000 million people in countries with agricultural water deficit" (p.19). Hoekstra and Chapagain (2008) were the first authors to establish a linkage between globalisation and water issues, and obtained the first evaluations of virtual trade. Liu et al. (2009) estimated consumptive green and blue water uses of 18 major crops on a global scale with a spatial resolution of 30 arc-minutes, and virtual water trade of these crops at the national level. They concluded that around 94% of the world crop-related virtual water trade has its origin in green water. Hanasaki et al. (2010) found that virtual water trade in just five commodities and three livestock products are equivalent to 545 km^3/yr. Of the total virtual water exports, 61 km^3/yr (11%) are blue water (i.e., irrigation water) and 26 km^3/yr, (5%) are non-renewable and nonlocal blue water.

However, participation in food trade is limited to a very short number of countries (See Table 4.1). The 15 largest importers (exporters) made up for 83.3% (78.3%) of exports (imports) in value terms in 2008. Food imports and exports to and from Africa represent only 3% of all word trade flows, although these flows are growing at about 22% per annum.

Issues

Globalisation associated with increased agricultural trade may be part of the transformation to a promising prospect to feeding the world. Especially for countries with very low water availabilities, food imports are an inevitable alternative to domestic agricultural production. Yang et al. (2003, 2007) highlighted that countries with lower water availabilities than a certain threshold are dependent on staple food imports in order to ensure sufficient feeding of their people. The following sections will reveal that the concept of virtual water trade from both perspectives, the importer's as well as the exporter's view, together with the influence of environmentally-based tariffs possibly implemented by the WTO, is subject to some controversy.

Lack of consistent conceptual basis for virtual water trade

Wichelns (2010) claims that, whereas the notion of virtual water trade has been effective in encouraging analysts and politicians to look at water issues, it lacks a conceptual underlying framework and should not be used alone as a criterion for selecting optimal policies. He reviews the literature debate on whether virtual water trade is a good indicator to guide policy decisions. Using graphical analyses of nations, Wichelns (ibid.) concludes that arable land in per capita terms is a better predictor of trading partners than water endowment.

Table 4.1: Leading exporters and importers of agricultural products, 2008 (billion dollars)

	Value	Share in world exports/imports				Annual percentage change			
	2008	1980	1990	2000	2008	2000-08	2006	2007	2008
Exporters									
European Union (27)	566.32	-	-	41.8	42.2	12	10	19	15
extra-EU (27) exports	127.63	-	-	10.1	9.5	11	13	16	17
United States	139.97	17.0	14.3	12.9	10.4	9	12	23	23
Brazil	61.40	3.4	2.4	2.8	4.6	19	13	22	27
Canada	54.08	5.0	5.4	6.3	4.0	6	7	10	11
China	42.29	1.5	2.4	3.0	3.2	13	13	19	9
Argentina	37.50	1.9	1.8	2.2	2.8	15	11	35	30
Indonesia	32.86	1.6	1.0	1.4	2.4	20	27	33	38
Thailand	31.66	1.2	1.9	2.2	2.4	13	21	16	27
Malaysia	27.80	2.0	1.8	1.5	2.1	17	16	32	35
Australia	26.14	3.3	2.9	3.0	1.9	6	5	1	17
Russian Federation	25.02	-	-	1.4	1.9	16	19	37	6
India	21.37	1.0	0.8	1.1	1.6	17	22	32	29
New Zealand	17.90	1.3	1.4	1.4	1.3	11	2	21	12
Mexico	17.56	0.8	0.8	1.6	1.3	9	15	8	13
Chile	15.61	0.4	0.7	1.2	1.2	12	14	19	14
Above 15	1117.47	-	-	83.6	83.3	-	-	-	-
Importers									
European Union (27)	611.75	-	-	42.4	43.3	12	9	21	15
extra-EU (27) imports	173.05	-	-	13.2	12.2	10	9	21	15
United States	115.91	8.7	9.0	11.5	8.2	7	8	6	6
China	86.83	2.1	1.8	3.3	6.1	20	14	27	33
Japan	80.63	9.6	11.5	10.4	5.7	3	-1	5	17
Russian Federation a	34.27	-	-	1.5	2.4	18	22	15	27
Canada b	31.24	1.8	2.0	2.6	2.2	9	13	14	11
Korea, Republic of	26.36	1.5	2.2	2.1	1.9	9	11	18	20
Mexico b	25.92	1.2	1.2	1.8	1.8	11	12	19	18
Hong Kong, China	16.50	-	-	-	-	4	7	13	23
retained imports	10.46	1.0	1.0	1.1	0.7	6	7	10	22
Saudi Arabia a	15.86	1.5	0.8	0.9	1.1	14	8	26	27
United Arab Emirates a	14.64	0.3	0.4	0.6	1.0	18	22	28	30
Malaysia	13.36	0.5	0.5	0.8	0.9	14	17	25	26
Indonesia	13.31	0.6	0.5	1.0	0.9	11	2	40	27
Turkey	13.04	0.1	0.6	0.7	0.9	15	12	35	33
Taipei, Chinese	12.55	1.1	1.4	1.3	0.9	6	2	12	16
Above 15	1106.12	-	-	82.0	78.3	-	-	-	-

a Includes Secretariat estimates.

b Imports are valued f.o.b.

Source: Taken from WTO's web page. Trade statistics.

Asink (2010) claims that “Unfortunately, virtual water trade cannot be applied to easily alleviate water scarcity or prevent water conflict. This is a caveat that should be taken into account in future work on virtual water trade. … I do not suggest that the concept of virtual water trade is flawed itself. The results of this paper do show, however, that the concept of virtual water has been used incorrectly to make claims that are not in line with empirical facts and standard economic theory” (p. 2031).

In the same vein, the fact that observed trade flows cannot be explained by the virtual water perspective has been posed by Kumar and Singh (2005) to conclude that trading strategies based on its postulates will not mitigate water scarcity.

In view of these and many other criticisms, one can identify a pattern in which economists tend to warn against the use of the concept for policy guidance, whereas geographers, hydrologists and modellers see a lot of potential in it.

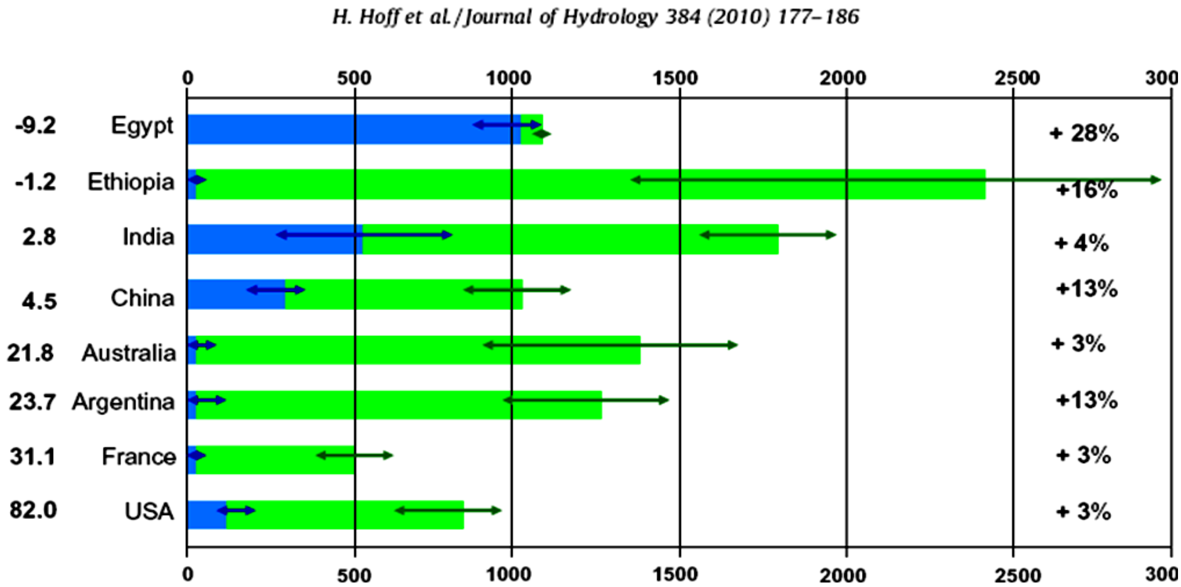
Increasing farm trade and its environmental effects on exporting countries

Hitherto, most virtual water trade studies have focused on its potential contribution to saving water, especially in water-short regions. Very little, however, has been said about the opportunity cost of the associated water used for agricultural production in exporting countries. Apart from emphasizing the trade’s potential to save water, it is also important to distinguish between the origins of water being used in the production of crops. In environmental terms, it is crucial to establish whether the water used originates from rainwater evaporated during the production process (green water) or from surface and/or groundwater sources evaporated as a result of the production of the product (blue water). Traditionally, emphasis has been given to the concept of blue water through the “miracle” of irrigation (Aldaya et al., 2010). However, for the analysis of sustainability aspects of international agricultural commodity trade, the green water component plays a crucial role. Green water differs from blue water in its scope of application and is generally associated with lower opportunity costs than blue water (Albersen et al., 2003). Green water cannot be automatically reallocated to uses other than natural vegetation or alternative rainfed crops, whereas blue water can be used for irrigating crops as well as for urban, agricultural and industrial water uses (Garrido et al., 2010). Furthermore, excessive irrigation can cause severe salinization, water logging and soil degradation, which are evident in many areas of the world (Postel, 1999).

From the viewpoint of opportunity cost of the use of water resources, trading green virtual water is overall more efficient than trading blue virtual water, holding other factors constant (Yang et al., 2006). Thus, the use of green water in crop production is considered more sustainable than blue water use, although this is not necessarily the case if blue water resources are not over-exploited (Garrido et al., 2010).

As a result, trade with an associated blue water saving but a greater green water loss could still be efficient from an economic and ecological point of view. There are huge differences in the contribution of blue and green water to the production of the same crops across the world (Figure 4.1).

Figure 4.1. Virtual water content (m^3/ton) of cereals, including green and blue water according to four modelling options. Source: Hoff et al. (2010).



To evaluate the environmental impacts of increased farm trade, not only water in virtual form should be analysed but also nutrient flows should enter the picture. Japanese scientists recognised the importance of this problem, describing serious nutrient disposal problems of nutrients that move in food commodities (Grote et al., 2008). Rockström et al. (2009) concluded that the world is operating well beyond the N-cycle's safety boundaries, but still within the safety boundaries in terms of fresh water use. Liu et al. (2010) made the first attempt to assess six N inputs and five N outputs in cropland on a global scale with a spatial resolution of 5 arc-minutes. They concluded that N scarcity is one key reason for food security problems in many African countries.

The coherence between trade liberalisation and sustainable food supplies

As it was previously stated, international farm trade may reduce the demand for scarce world water resources. The trade liberalisation process that has been targeted by the Doha-Round since 2001 will likely lead to further growth of agricultural trade flows (Reimer, 2010). This involves the chance to increase global food security accompanied by regional and global water savings and welfare gains. However, trade liberalisation is unambiguously welfare-improving and environmentally friendly only if property rights are well defined. This is rarely the case, especially for developing countries (Berrittella et al., 2008). Thus, whether this strategy is economically optimal will depend on whether the water opportunity cost and production's externalities are properly internalised. Although water is already scarce in many countries, improvements to achieve this internalisation of negative external effects by economizing water markets are proceeding slowly. The current level and structure of water charges mostly do not encourage farmers to a more efficient water use. Very often irrigation water is offered at subsidised rates (Garrido and Calatrava, 2009; Berrittella et al., 2008). Thus, trade liberalisation generally leads to an enhancement of sustainable food supplies if food commodity prices reflect the full costs. Based on this, water and trade policies could be enhanced by integrating environmental concerns in both importing and exporting countries.

De Fraiture (2004) cautions against the conclusion that trade is helpful to mitigate global water scarcity, because water savings cannot be re-allocated to more beneficial uses. And Molle and Berkoff (2007) suggest that expectations from irrigation water pricing policies, especially in developed countries, should be limited.

Methods

We have taken into account the imports and exports of five Latin American countries, namely Argentina, Brazil, Chile, Mexico and Peru for which FAOSTAT provided production data as well as trade data. In a first step, the crops were ordered using the 11 year average, looking at the area harvested in hectares, production in tons, imports and exports in tons. Yield is given as additional information. Crops that are most relevant in each category are analysed in light of the stated research questions.

Development of the agricultural market

The paper reflects on changes of the agricultural market by depicting variances of import and export volumes of the most traded goods in all 5 countries. In order to explain the evolving trade flows, potential alterations in production data as well as expanding areas harvested are assessed.

Origin of water for crop production

The virtual water content of a product consists of three components: green, blue and grey water. At the present time we only distinguish between green and blue water for our analysis though. This differentiation is very policy relevant because the various water components have different characteristics. The use of green water is considered as more sustainable, because its opportunity costs are very low. The opportunity costs of blue water depend on the scarcity level in each region (Garrido et al., 2010).

We want to give an overview of which crops are grown under rainfed and which under irrigated conditions. To determine the area harvested under irrigated and rainfed conditions, we subtract the irrigated area harvested per crop from the total area harvested of the respective crop and thus obtain the rainfed area harvested per crop. Subsequently we calculate the ratio of rainfed areas and irrigated areas per crop in each country.

Data

Data related to crop area, production and yield were taken from FAO (2010). Crop data refer to 1997-2007 and are at national level. Data on trade in crops were obtained from FAO (2010). These data were taken at the national level for 1997-2007. Information on irrigated area harvested per crop per country was available for the year 2000 on a national level. The data was obtained from AQUASTAT (2010) which is FAO's Information System on Water and Agriculture.

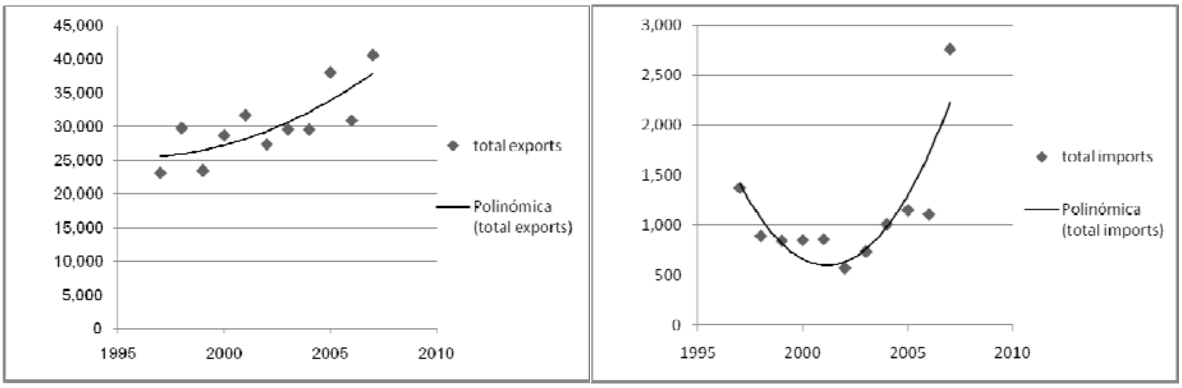
Results

The results of the above described issues are presented for the countries Argentina, Brazil, Chile, Mexico and Peru.

Argentina: A net agricultural exporter

Argentina is a net exporter of agricultural products. Previous studies, such as the one from Hoekstra (2005) and Chapagain (2004), proved that these trade flows imply large virtual water exports in Argentina. Figure 4.2 shows that exports in Argentina have had a steady upward trend during the last decade which is likely to be remained in the future. Nevertheless also total agricultural imports have increased since 1997 to 2007. After a sharp drop in imports in the years 1998 and 2002, imports have been vigorously increasing until 1997.

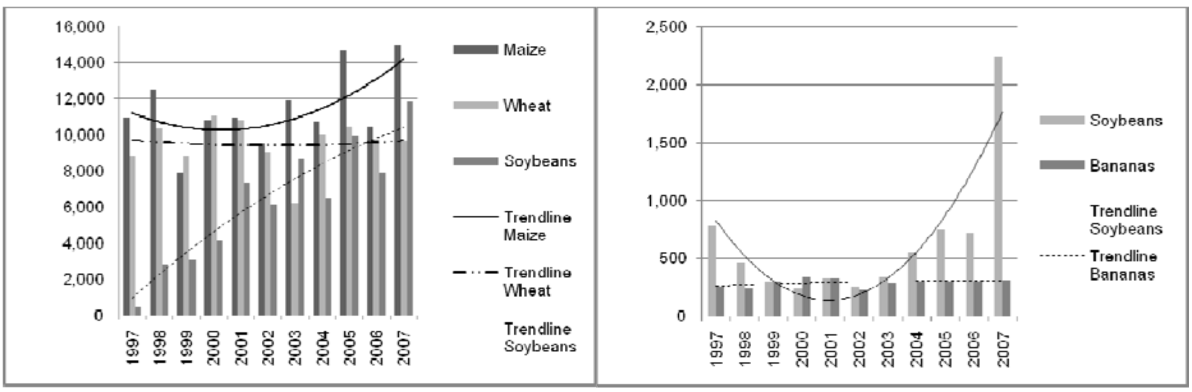
Figure 4.2. Total exports (left) and imports (right) of agricultural products in Argentina (in thousand tons).



Source: own elaboration

Crops with the highest export amounts, shown in Figure 4.3, are maize, wheat and soybeans making up almost 90% of total crop exports. Export volumes of soybeans but also of maize and wheat have recorded very high growth rates since 1997. Soybean exports have gained the most during the last decade, but also maize exports have increased especially during the last years. Wheat exports have stagnated on a high level (see Figure 4.3)

Figure 4.3. International trade of Argentina (exports (left) and imports (right) in thousand tons).

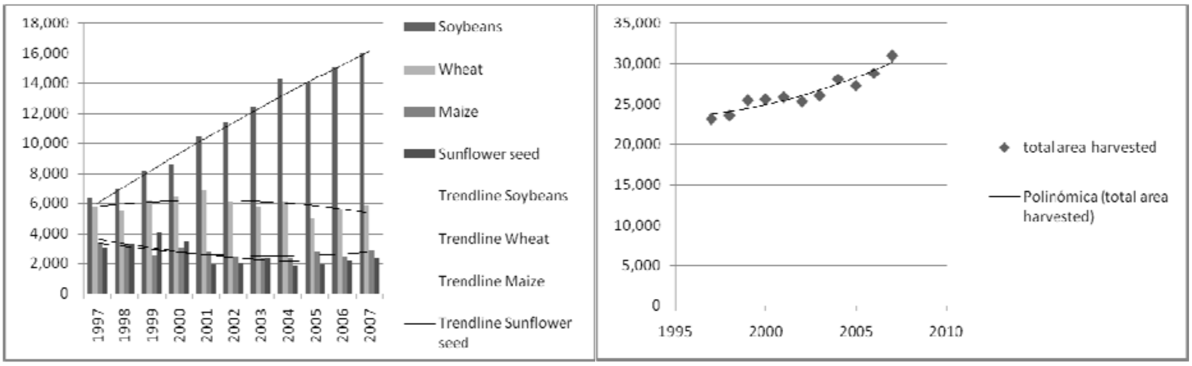


Source: own elaboration

The import market is dominated by soybeans and Bananas, adding up in average to almost 85% of all crop imports. This tendency reveals again the growing importance of soybeans as a global product. Especially the sharp increase in total agricultural imports (see Figure 4.2) can be explained by the soybean market. Banana imports seem to be stable (see Figure 4.3). Green coffee and vegetables also belong to the group of most imported products in Argentina, although on a much lower level and with a rather declining tendency.

Figure 4.4 illustrates that the increase in (virtual water) exports of soybeans have mainly been resulting from an expansion of farm land, more than doubling in the period 1997-2007. Yields in soybean production have not been significantly growing in Argentina. Again it can be stated that farm land increases mainly result from the expansion of soybean production.

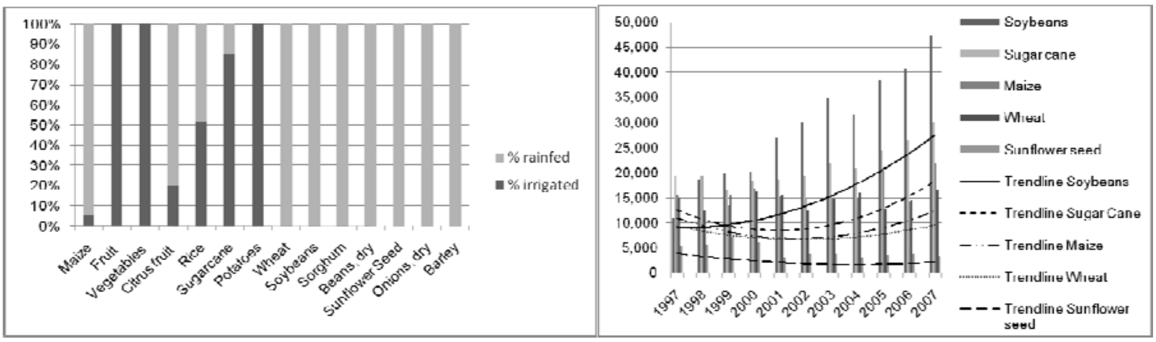
Figure 4.4. Area harvested of selected crops in Argentina (in thousand ha).



Source: own elaboration

From a sustainability point of view, it is worth while differentiating between rainfed and irrigated agricultural production. Figure 4.5 demonstrates that products mainly produced for the export market, namely soybeans, wheat and maize are almost entirely grown under rainfed conditions. Sorghum and barley, also important export products, are also entirely grown under rainfed conditions. Only fruits that make up only a few per cent of total production and exports are entirely irrigated.

Figure 4.5. Irrigated and rainfed area harvested in Argentina (left) (in thousand ha in year 2000); crops with highest production volume in Argentina (right) (in thousand tons).

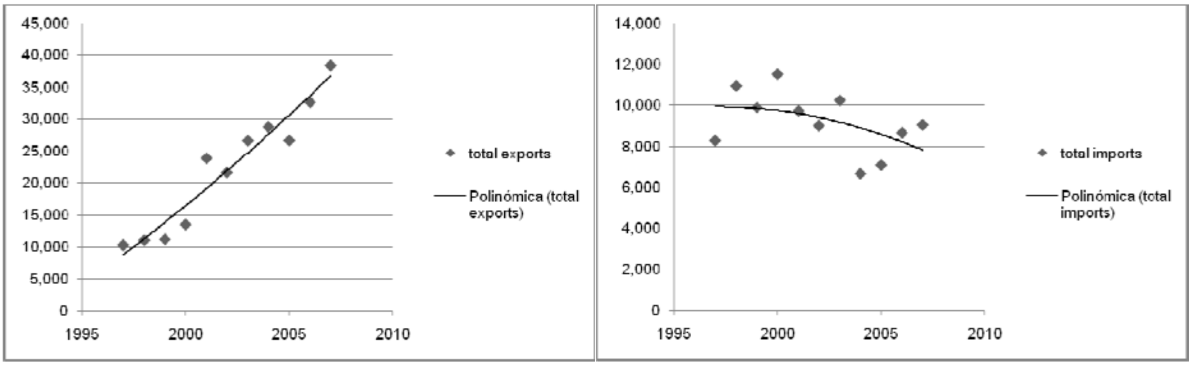


Source: own elaboration

Brazil: A net agricultural exporter

Brazil is a very large international trade participant. Crop exports amount to 22 million tons on average between 1997 and 2007, against average imports of 9 million tons during that time period. Figure 4.6 illustrates the increasing importance of the export market in Brazil. Within 11 years crop exports have more than tripled. With slightly declining imports, Brazil has turned into a significant net exporter over the years.

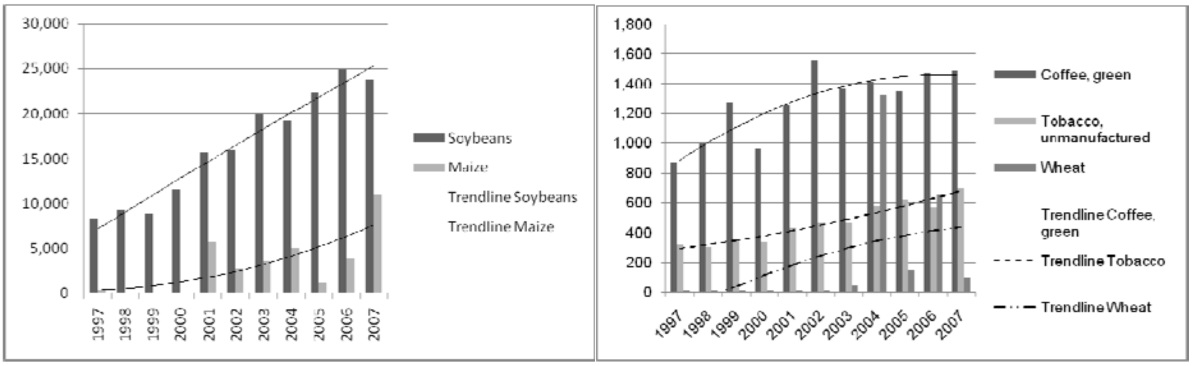
Figure 4.6. Total exports (left) and imports (right) of agricultural products in Brazil (in thousand tons).



Source: own elaboration

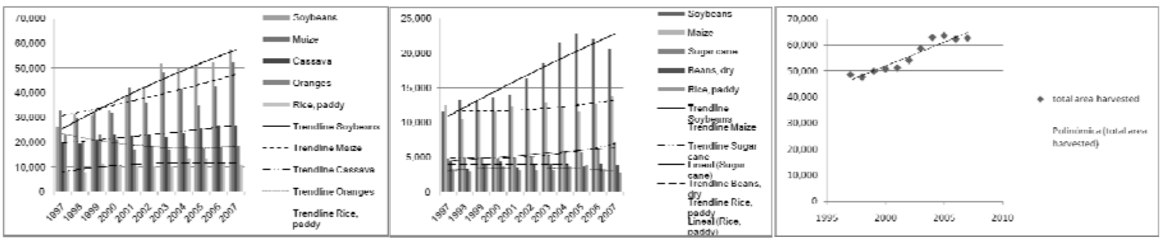
Especially, soybeans and maize have been increasingly produced for the export market. Nevertheless green coffee, tobacco and wheat exports are also expanding. Soybeans and Maize exports have tripled within 11 years (see Figure 4.7).

Figure 4.7: Brazilian exports (in thousand tons).



Source own elaboration

Figure 4.8. Crops with highest production volume in Brazil (left) (in thousand tons), area harvested of selected crops in Brazil (middle) (in thousand ha) and total area harvested in Brazil (right) (in thousand ha).

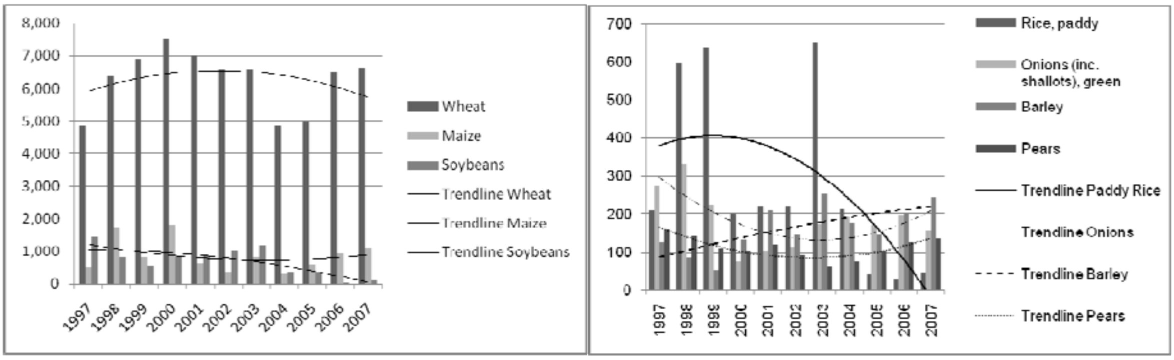


Source: Own elaboration

The escalation of the soybeans and maize production for the export market results from an expansion of farm land whereas yields have been observed as being constant over the last decade. Figure 4.8 illustrates that the increase of total area harvested in Brazil mainly results from the steep rise of soybean production.

Looking at Brazil's imports the major crops have always been wheat, maize and soybeans on average making up 87% of imported food crops between 1997 and 2007. Total food imports have been relatively stable at a level of approximately 9 million tons per year. In line with this trend is also the slightly decreasing import amounts of wheat, maize and soybeans (Figure 4.9). Although other products, such as onions, barley and pears show slightly increasing import amounts, their import magnitude is relatively low (Figure 4.9).

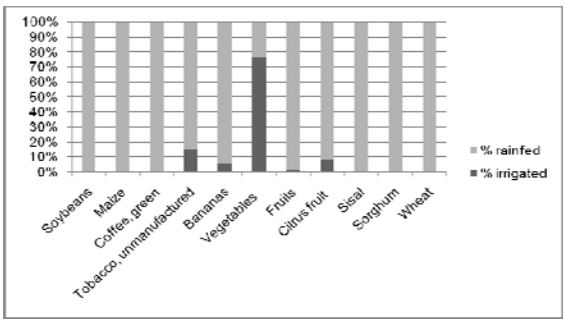
Figure 4.9. Brazilian imports (in thousand tons).



Source: own elaboration

The green and blue water distribution among those crops shows that the main export products, namely soybeans, maize, green coffee and tobacco are entirely grown under rainfed conditions. Only about 15% of the tobacco's area harvested, in total only amounting to less than 1% of total area harvested, is grown under irrigated conditions. Also vegetables that are to a large part grown under irrigated conditions are negligible in terms of exports and area harvested (see Figure 4.10).

Figure 4.10. Irrigated and rainfed area harvested in Brazil (in thousand ha, year 2000).

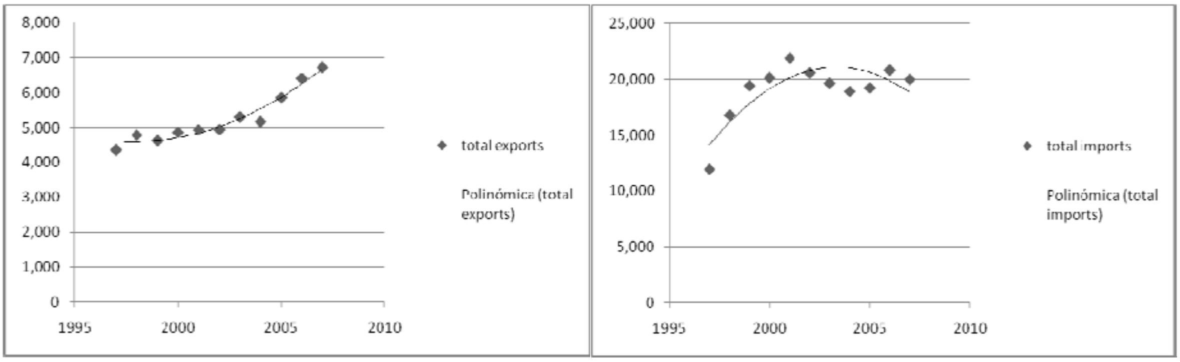


Source: own elaboration

Mexico: A net agricultural importer

Mexico is a net importer of agricultural products, implying high volumes of virtual water imports. Figure 4.11 shows the overall trend of Mexico's trade flows, illustrating that not only imports but also exports have grown significantly. In absolute terms, Mexico still imports much more than it exports. Imports being at a level of almost 20 million tons in 2007 (almost 12 million tons in 1997) and exports being at a level of 6.7 million tons in 2007 (almost 4.4 million tons in 1997), most likely Mexico will maintain its net importing position in the future.

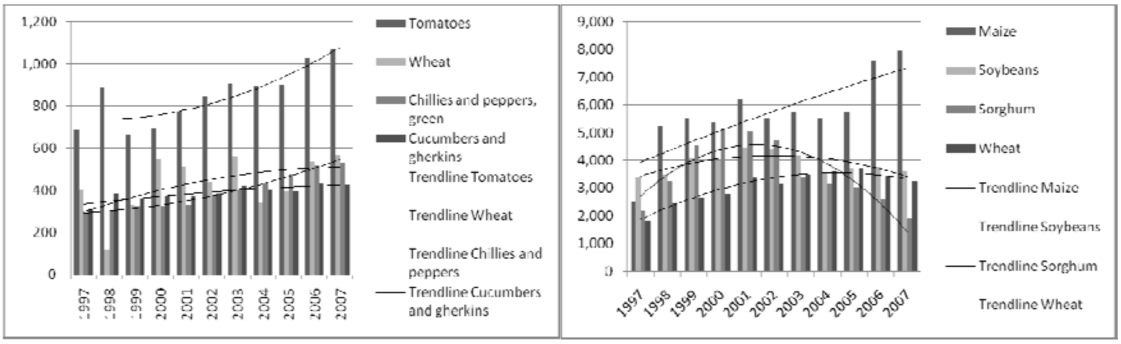
Figure 4.11. Total exports (left) and imports (right) of agricultural products in Mexico (In thousand tons).



Source: own elaboration

Crops with the highest export amounts, shown in Figure 4.12, are tomatoes, wheat, green chillies and peppers as well as cucumbers and gherkins. Those products make up almost 40% of total crop exports. Adding fruits and vegetables as well as green coffee, amounts to more than 75% of all exported crops. The export activities for fruits and especially vegetables have increased significantly during the last decade.

Figure 4.12. International trade of Mexico (exports (left) and imports (right) in thousand tons).

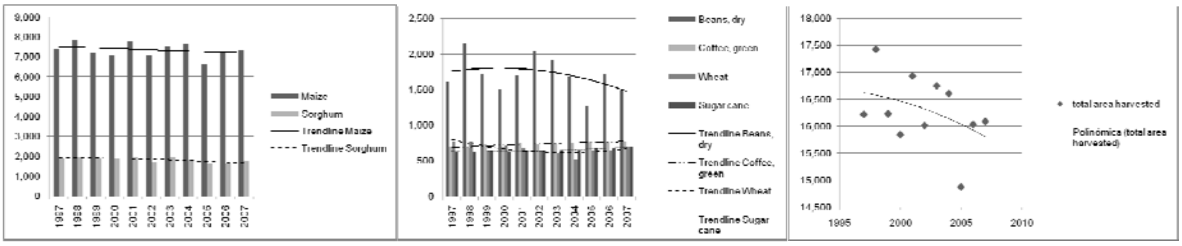


Source: own elaboration

The import market is dominated by maize, soybeans, sorghum and wheat, amounting to 85% of all crop imports during 1997 and 2007. Maize imports have grown with a linear trend during this time. Wheat grew slightly each year, though it levelled off in the last years of the series. Soybean and sorghum imports increased until 2001, but are declining since then and are almost back to the level of 1997.

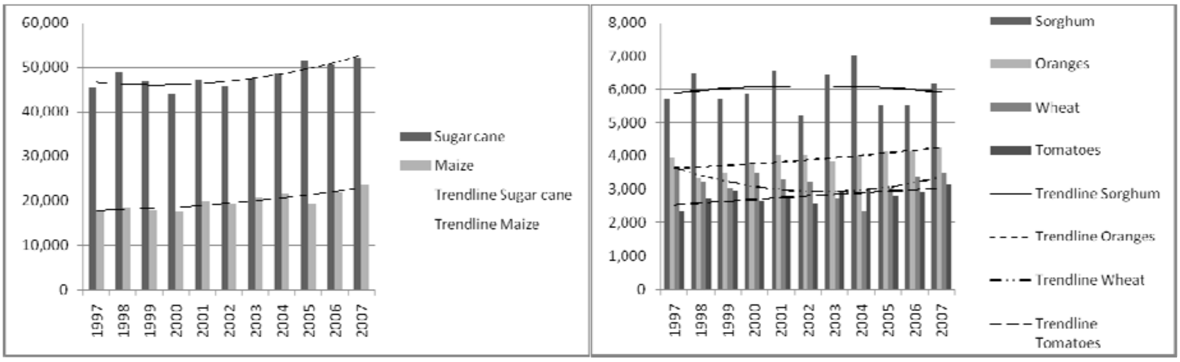
Figure 4.13 illustrates that there is a general decrease in area harvested in Mexico. Production however is very stable or even slightly increasing (see Figure 4.14), which leads to the assumption that productivity has been improved in Mexico.

Figure 4.13. Area harvested of selected crops in Mexico (in thousand ha).



Source: own elaboration

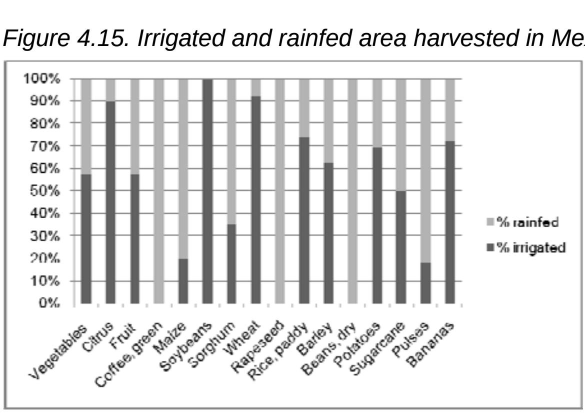
Figure 4.14. Crops with highest production volume in Mexico (in thousand tons).



Source: own elaboration

Figure 4.15 gives an overview of areas that grow crops under rainfed and irrigated conditions. It is clear that many Mexican agricultural areas depend on irrigation. Therefore the use of blue water in agricultural production for the domestic and export market is very high. Vegetables are grown under irrigated conditions to almost 58%. Wheat as the second largest export product is almost entirely irrigated. Also the most relevant imported goods, such as maize, sorghum, soybeans and wheat would have been grown with irrigation if Mexico had produced them itself.

Figure 4.15. Irrigated and rainfed area harvested in Mexico (in thousand ha, year 2000).

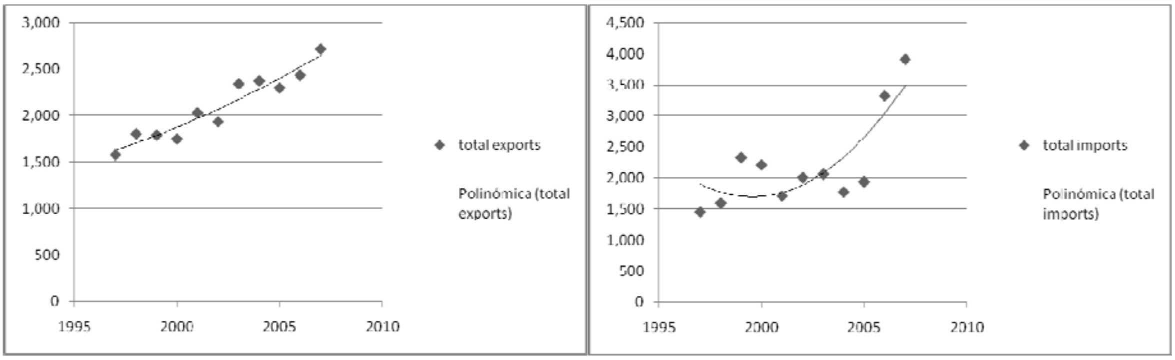


Source: own elaboration

Chile: An exporting-importing country

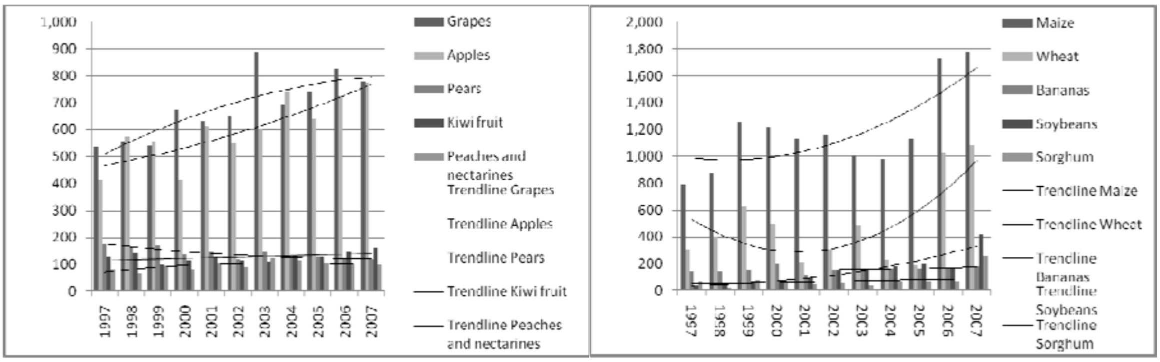
Figure 4.16 plots Chilean's commodities imports and exports from 1997-2007 with a clear trend upwards. Total crop exports and imports have approximately the same magnitude. The growth in both cereal imports and fruits exports is clear (see Figure 4.17).

Figure 4.16. Total exports (left) and imports (imports) of agricultural products in Chile (in thousand tons).



Source: own elaboration

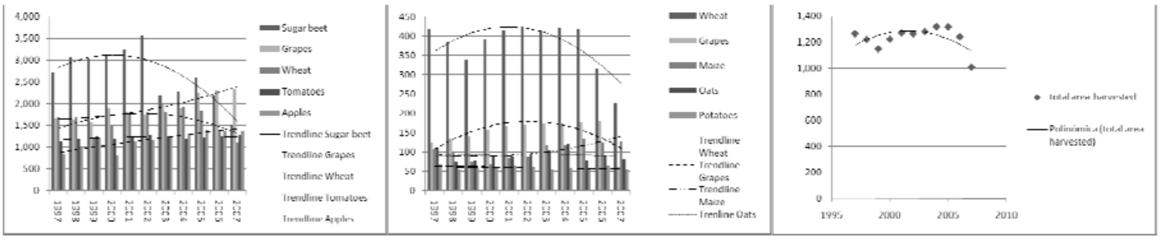
Figure 4.17. International trade of Chile (exports (left) and imports (right) in thousand tons).



Source: own elaboration

Figure 4.18 shows that total crop production in Chile varies between 13 million and 15 million tons per year with a shift away from cereals towards fruit production. This result is in line with the development of Chile's trade activities. Harvested area has stabilised in the range of 1.2 to 1.3 million hectares in Chile.

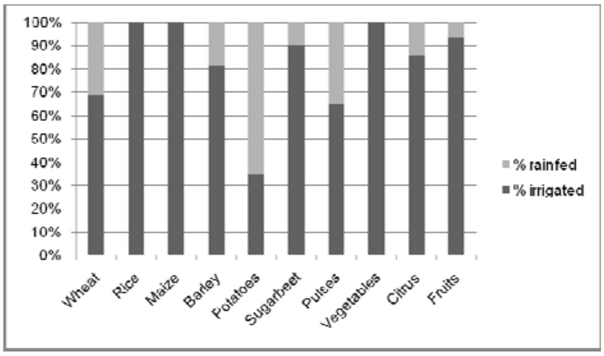
Figure 4.18. Crops with highest production volume in Chile (left) (in thousand tons), area harvested of selected crops in Chile (middle) (in thousand ha) and total area harvested in Chile (right) (in thousand ha).



Source: own elaboration

Figure 4.19 plots the harvested areas under rainfed and irrigated conditions. It is clear that Chile's agriculture, especially fruits produced for the export market are irrigated. However, also wheat and maize with high production volumes are primarily grown under irrigated conditions.

Figure 4.19. Irrigated and rainfed area harvested in Chile (year 2000).

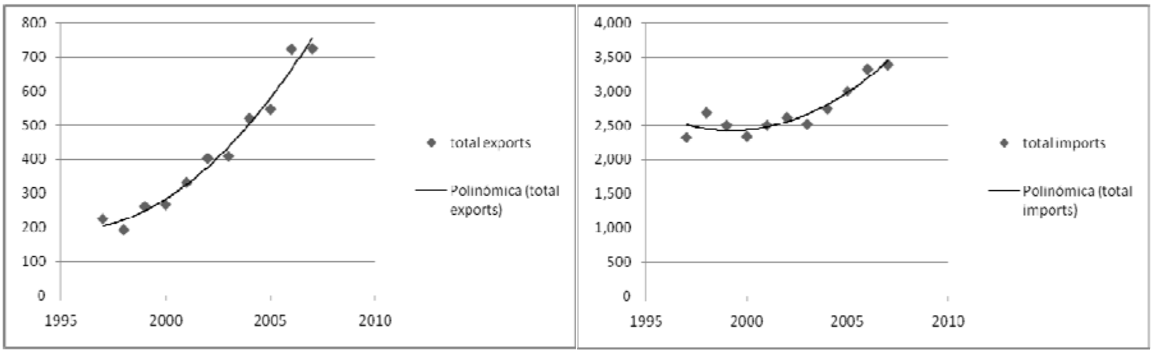


Source: own elaboration

Peru: An exporting-importing country

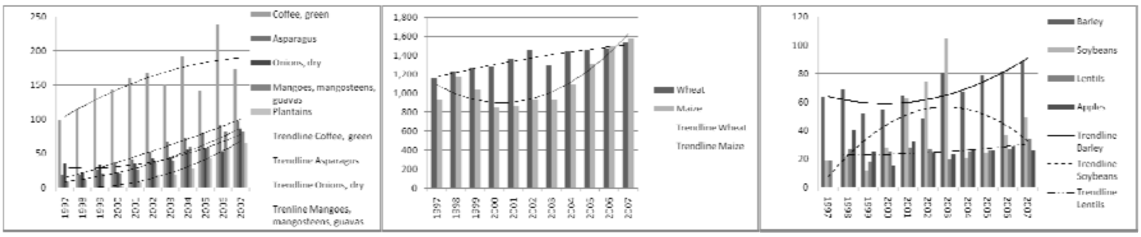
Figure 4.20 plots Peruvian's total agricultural commodities imports and exports from 1997-2007 with a clear trend upwards. Total imports have grown approximately by one third during this time, whereas exports have almost tripled. Therefore Peru has developed from a net agricultural importer to a net exporter in crops. The growth in both cereal imports and fruits exports is clear (see Figure 4.21).

Figure 4.20. Total exports (left) and imports (right) of agricultural products in Peru (in thousand tons).



Source: own elaboration

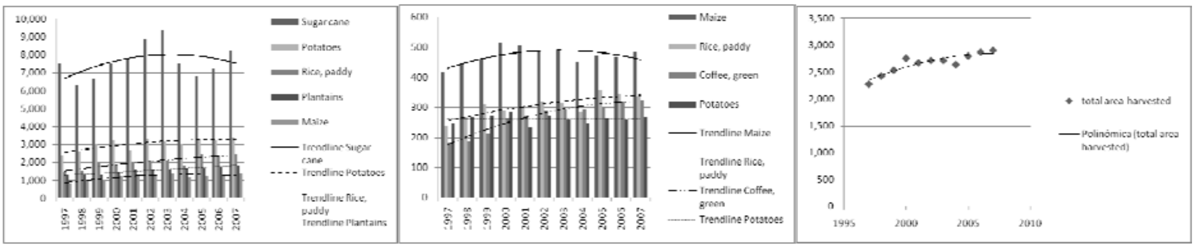
Figure 4.21. International trade of Peru (exports (left) and imports (2 on the right) in thousand tons).



Source: own elaboration

Figure 4.22 depicts that total crop production in Peru is growing from 19 million tons in 1997 to 25 million tons in 2007. Harvested area in Peru has grown from 2.3 million hectares to 2.9 million hectares in the same period. Although fruits are more and more counted among the most important export crops of the country, cereals still amount up to more than 80% of total production and 85% of total area harvested.

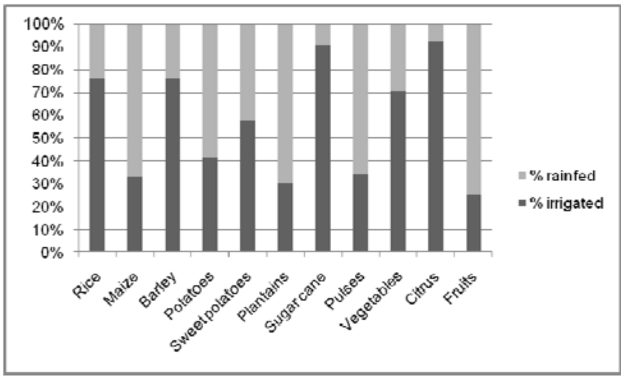
Figure 4.22. Crops with highest production volume in Peru (left) (in thousand tons), area harvested of selected crops in Peru (middle) (in thousand ha) and total area harvested in Peru (right) (in thousand ha).



Source: own elaboration

Figure 4.23 plots the harvested areas under rainfed and irrigated conditions. It is clear that Peruvian's agriculture is highly irrigated. Sugar cane, potatoes, rice, plantains and maize that make up 70% of total crop production are all grown under irrigated conditions to a certain extend. Fruit and vegetable production for the export market are also produced under irrigation.

Figure 4.23. Irrigated and rainfed area harvested in Peru (year 2000).



Source: own elaboration

Discussion

This section attempts to bring the evaluations reported in the results section to the policy context, by interpreting the results in light of the research questions. For all analysed Latin American countries, namely Argentina, Brazil, Mexico, Peru and Chile, trade activity has increased vigorously. This tendency of increasing productive specialisation is a result of a proceeding trade liberalisation process and will likely continue in this direction (Ramirez-Vallejo and Rogers, 2004; Martin, 2010).

The results from Argentina and Brazil show that those countries are progressively becoming part of the food basket of the world. Being major exporters of agricultural commodities, it is clear that they contribute to feeding the world. Besides maize, the most important exported product is soybeans in both Argentina and Brazil (proteins and hydrocarbons for animal feed are effectively the goods these two products represent). In Argentina soybeans are even the largest imported good, but this may represent imports from Paraguay, Uruguay or Brazil that are re-exported by Argentina. This tendency reflects the global evolution towards a more meat oriented diet since soybeans serve as animal feed all over the world, especially monogastrics (chicken and pigs). Therefore soybean production is necessary to achieve the goal of a global food security with a balanced diet. Argentina's and Brazil's agricultural export markets are clearly based on this development. To answer the question of whether this contribution to global food security also meets the standard of sustainable water use, we distinguished between green and blue water resources in the production process.

In Argentina as well as Brazil the main exported products are grown under rainfed conditions which enable production at a lower opportunity cost. This implies that virtual water exports are in line with an environmental friendly production and thus can continue in a sustainable way. However, increasing soybean production has led to a massive farm land expansion in both countries. If the magnitude of exports continues to increase with the same speed than in former times, they may hit environmental limits. Not only the availability of land but also the availability of water in those areas constitutes a ceiling of increasing export activities. In the case of Brazil for the time being land availability is not a crucial constraint though. There is a potential of 300 million to 400 million hectares of arable land, so far using only 50 million hectares. Brazil also has a vast amount of renewable water resources that can be used for agricultural production. It should be added that this potential arable land and water resources are not mainly located in the ecosystem sensitive area of Amazonia but rather in the "cerrado" (*The economist, 2010*). In conclusion Brazil has an immense potential to help feed the world sustainably. Thus, virtual water trade can contribute to that goal. Producing within environmental limits and exporting the products to more constrained areas of the world helps promoting global food security and alleviating regional water stress. The effects of expanding area harvested for soybean production also affects the production of other products though. There is more research needed in the field of land use change to make a final conclusion whether this amplified production is sustainable.

As stated above, not all countries have such an excess of natural resources and rely on the world food markets. We showed that increased food trade can contribute to more food security in importing semi-arid countries. Looking at Mexico as a major food importer, reduced farm trade by closing up the markets would have severe consequences for the country's food security as well as for the relatively scarce water resources. If Mexico had to produce all its imported crops itself, it would have to use valuable blue water resources. Since Mexico's agricultural crops are in many parts grown under irrigated conditions, it can be stated that virtual water trade alleviates Mexico's water stress. Even though total annual renewable water resources exceed by far the total annual withdrawals, the spatial distribution of water availability may not be in accordance with the agricultural production area. Also most rivers in Mexico are of pluvial origin and flows vary over the year according to rainfall pattern, creating uncertainty of water availability. Nevertheless Mexico's progressing agricultural market liberalisation, especially through the North American free trade agreement (NAFTA), also has its downsides from an environmental perspective. Cereals being produced to a larger part under rainfed conditions are increasingly imported whereas irrigated vegetables are becoming the main export products. Whether or not the cost of the potential overexploitation is well reflected in the market price of the products is questionable. This would lead to unsustainable virtual water trade flows. This might be a reason why exports are growing much faster than imports. Yet the declining harvested area with slightly increasing production amounts leads to the assumption that productivity is still rising. Therefore Mexico still has potential to distend its agricultural markets.

Chile and Peru are much smaller market participants, though with increasing import and especially export amounts. Most of the exports are produced with blue water, and some of their most semi-arid river basins are perhaps suffering the pressure of irrigation water abstractions. It is questionable if Peru with its climatic conditions can establish its high export growth rates in the future without risking overexploitation. The same holds for Chile. Although in Chile area harvested is even decreasing and production has stabilised. Therefore simply more products have been sold on global markets instead of domestic markets not effecting water resources. Peruvian's harvested area has only increased slightly. Therefore production expansion of fruits for the export markets didn't need new agricultural land.

The results show that enhanced virtual water trade in Latin American countries has the potential to accomplish a more sustainable future combined with global food security. Therefore, the trade liberalisation process should be pushed further forward to facilitate trade actions. Although to really achieve this sustainability goal, trade liberalisation should only be implemented in conformity with environmentally standards. As described earlier in this paper, water pricing strategies play a crucial role. The four main types of responses to higher water prices are the use of less water on a given crop, the adoption of water conserving irrigation technologies, shifting water usage to more water-efficient crops, and the change in a crop mix to higher valued crops (Rosegrant, 2009; Ringler, 2000). However, there is a standing tradition in Latin American countries of heavily subsidizing irrigation water. Water users therefore have little incentive to economise on its use. In Mexico and Peru, for example, unrealistically low water tariffs may have encouraged farmers to grow cereals, roots and livestock on irrigated lands in direct competition with small rainfed producers, crowding them out of the most dynamic markets or limiting their access to them (Ringler, 2000). This circumstance leads to an inefficient water use and involves the risk of unsustainable water uses. Recent changes in water tariffs in Mexico attest for the Government's clear determination to increase the cost recovery rates (Garrido and Calatrava, 2009). A successful example of the implementation of water pricing is Chile. This country adopted a comprehensive, market oriented water policy nearly twenty years ago and has achieved improvements in water use efficiency. Tradable water rights in Chile have fostered efficient agricultural water use, which has in turn increased agricultural productivity, generating more production per unit of water. The market valuation of water at its scarcity value has induced investments in on-farm irrigation technologies which have saved water. This amount of water can be used to irrigate other areas or to sell it to other users. Moreover, it has induced a shift to high-valued crops, which use less water per unit or value of output. Also the assessment of shadow prices of water gives farmers a greater flexibility to shift cropping patterns according to market demand through the purchase, rent and lease of water (Ringler, 2000).

The virtual water concept is globally relevant and connected to international farm trade. This raises the question of whether the implementation of environmentally-based tariffs should be introduced by the WTO to penalise unsustainably produced food exports. Although the WTO claims that its goal of promoting free trade is not contradictory to environmentally friendly trade, the reality reveals a different picture. Internationally binding agreements on sustainable water use in the production of goods do not exist (Hoekstra, 2010). Also the WTO's main principle of non-discrimination involves the risk of rejecting environmentally friendly approaches of agricultural trade (Tarasowfsky and Palmer, 2006). Therefore, accordingly to Hoekstra (2010), binding multilateral rules should be established to remedy the market failure of not-internalised external effects of production of traded goods. Different economic studies dealing with the implementation of water pricing show that it is an adequate mechanism to shift production away from water intensive products to water extensive products if water is a scarce input factor in that region (Berrittella, 2008; Bartolini, 2007; Merrett, 2004). These studies however show only the effects of unilateral water pricing. Without an international treaty on proper water pricing, reflecting the water scarcity rents of the different regions, it is unlikely that a globally efficient pattern of water use can be achieved. The sustainable use of the world's water resources can only be promoted with the existence of such an international protocol on full-cost water pricing, because water scarcity would automatically translate into a scarcity rent and thus affect consumer decisions, regardless of the product's origin and destination (Hoekstra, 2010). This could contribute to solving regional water problems by shifting trade flows in an optimal way. However there have been doubts about whether the WTO is the appropriate organisation of promoting environmental sustainability. Rogers and Ramirez-Vallejo (2010) state that the problems of unsustainability should be solved nationally with water economic tools and not with trade regulations.

Conclusions

International farm trade is already substantial and is likely to increase further with continued global trade liberalisation (Ramirez-Vallejo and Rogers, 2004). As a consequence also water in its virtual form is transported around the world.

The paper has shown that intensified trade offers both opportunities and risks. One major opportunity of virtual water trade lies in its capability to release pressure on domestic water resources in water scarce areas. Mexico, Chile and Peru are illustrative of those countries where virtual water imports are a cheap alternative source of water. This case proved that virtual water trade has the potential to help achieving the goal of global food security, resulting in the necessity to proceed with the trade liberalisation process.

Furthermore the effects of increased farm trade on environmental aspects in exporting countries were analysed. The examples of Argentina and Brazil have shown that agricultural production practices for export commodities are usually in line with environmental requirements. The predominant use of green water instead of blue water in those water abundant regions has enabled sustainable virtual water exports. However, more research is needed on the effects of land use change.

To guarantee sustainable trade flows in the future on a global level, negative external environmental effects should be internalised though. This gap of multilateral commitment is debated within the scope WTO's environmental regulations.

It is essential to do further research on the concept of virtual water trade as a tool for feeding the world sustainably in the future. Latin America, containing very large exporters and importers of the world should be investigated more precisely. Research on sub-national level will be essential to answer the question if agricultural production standards do not ignore environmental issues. To answer this question properly, grey water should also be included in future research. Additionally, it should be mentioned that this study only presents preliminary results. Especially the questions regarding the effects of environmentally based tariffs implemented by the WTO should be treated in more detail. To get a better understanding of this issue and to specify policy implications, the economic value of water and land in the focal countries needs to be determined. Subsequently an analysis of how water pricing would shift agricultural production and trade flows would follow. This allows us to answer the important question of how to feed the world in a sustainable way, perhaps enforced with the support of WTO rules.

References

Aquastat (2010) FAO's Information System on Water and Agriculture.

Faostat (2010) Food and Agriculture Organization of the United Nations.

Affuso, E. (2010) International virtual water trade: A theoretical and empirical market analysis, SSRN eLibrary.

Albersen, P. J., Houba, H. E. D. and Keyzer, M. A. (2003) Pricing a raindrop in a process-based model: General methodology and a case study of the upper-Zambezi, Physics and Chemistry of the Earth, 28: 183-192.

Aldaya, M. M., Allan, J. A. and Hoekstra, A. Y. (2010) Strategic importance of green water in international crop trade, Ecological Economics, 69: 887-894.

Allan, J. A. (1998) Virtual water: A strategic resource global solutions to regional deficits. Ground Water, 36: 545-546.

Ansink,E.(2010) Refuting two claims about virtual water trade, Ecological Economics, Volume 69, Issue 10, 15 August 2010, Pages 2027-203.

Bartolini, F, Bazzani, G.M., Gallerani, G.V., Raggi, M. and Viaggi, D. (2007) The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models, Agricultural Systems, 93: 90-114.

Berrittella, M., Rehdanz, K., Roson, R. and Tol, R.S.J. (2008) The economic impact of water pricing: A computable general equilibrium analysis, Water Policy, 10: 259-271.

Chapagain, A; K. and Hoekstra, A.Y. (2004) Water footprint of nations, In: Hoekstra, A.Y. (ed.), Value of Water Research Report Series Main Report, UNESCO-IHE, Delft, the Netherlands.

Falkenmark, M. and Lannerstad, M. (2010) Food security in water-short countries – Coping with carrying capacity overshoot, In Martinez Cortina, L., Alberto Garrido, and Elena Lopez-Gunn. (Eds.), Re-thinking water and food security: Fourth Marcelino Botin Foundation Water Workshop, Taylor & Francis, Leiden. 2010, 3-22.

Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M. and Molden, D. (2004) Does international cereal trade save water? The impact of virtual water trade on global water use, Comprehensive Assessment Research Report 4, IWMI, Colombo, Sri Lanka.

Garrido, A., Novo, P., Rodríguez-Casado, R., Varela-Ortega, C. and Aldaya, M. M. (2010) Economic aspects of virtual water trade: Lessons from the Spanish case, In Martinez Cortina, L., Garrido, A. and Lopez-Gunn, E. (Eds.) Re-thinking Water and Food Security: Fourth Marcelino Botin Foundation Water Workshop. Taylor & Francis, Leiden. 145-159.

Garrido, A., M.R. Llamas, C. Varela-Ortega, P. Novo, Rodríguez-Casado, R. and Aldaya, M.M. (2010) Water footprint and virtual water trade in Spain, Springer, New York.

Garrido, A. and Calatrava, J. (2009) Agricultural water pricing: EU and Mexico, OECD. Paris. www.oecd.org/dataoecd/25/38/45015101.pdf.

Grote, U. Craswell, E.T and Vlek, P.L.G. (2008) Nutrient and virtual water flows in traded agricultural commodities, Land Use and Soil Resources: 121-143.

Hanasaki, N., Inuzuka, T., Kanae, S. and Oki, T. (2010) An estimation of global virtual water flows and sources of water withdrawal for major crops and livestock products using a global hydrological model, Journal of Hydrology 384, (3-4): 232-244.

Hoekstra, A. Y. (2010) The relation between international trade and freshwater scarcity. In: Hoekstra, A. Y. (Ed.), WTO Staff Working Paper ERSD-2010-05, Geneva.

Hoekstra, A. Y. and Hung, P. Q. (2005) Globalisation of water resources: International virtual water flows in relation to crop trade, Global Environmental Change-Human and Policy Dimensions, 15: 45-56.

Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L. and Rockström, J. (2010) Greening the global water system. Journal of Hydrology 384 (3-4): 177-186.

Liu, J. and Savenije, H.H.G. (2008) Food consumption patterns and their effect on water requirement in China, .Hydrology and Earth System Sciences, 12: 887-898.

Liu, J., Yang, H. and Savenije, H.H.G. (2008) China's move to higher-diet hits water security, Nature 454 (7203): 397.

Liu J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A. J. B. and Yang, H. (2010) A high-resolution assessment on global nitrogen flows in cropland, PNAS 107 (17): 8035-8040.

Liu, J., Zehnder, A.J.B. and Yang, H. (2009) Global consumptive water use for crop production: The importance of green water and virtual water, Water Resources Research, 45, W05428, doi:10.1029/2007WR006051.

Martin, W. and Mattoo, A. (2010) The Doha development agenda: What's on the table?, Journal of International Trade & Economic Development, 19: 81-107.

Merrett, S. (2004) The potential role for economic instruments in drought management, Irrigation and Drainage, 53: 375-383.

Molle F. and J. Berkoff (Eds.) (2007) Irrigation Water Pricing Policy in Context: Exploring the Gap between Theory and Practice, Wallingford,UK,. CABI and IWMI, 295-327.

Nordström, H. and Vaughan, S. (1999) Trade and environment, In: Special studies 4, Geneva: World Trade Organisation (WTO).

Novo, P., Garrido, A. and Varela-Ortega, C. (2009) Are virtual water "Flows" in Spanish grain trade consistent with relative water scarcity?, Ecological Economics, 68: 1454-1464.

Postel, S. (1999) Pillar of sand: Can the irrigation miracle last?, Issues in Science and Technology, 16: 84-87.

Ramirez-Vallejo, J. and Rogers, P. (2004) Virtual water flows and trade liberalization, Water Science and Technology, 49: 25-32.

Reimer, J. J. and Li, M. (2010) Trade costs and the gains from trade in crop agriculture, American Journal of Agricultural Economics, 92: 1024-1039.

Ringler, C., Rosegrant, M. W. and Paisner, M. S. (2000) Irrigation and water resources in Latin America and the Caribbean: Challenges and strategies, EPTD Discussion Papers, Inter-American Development Bank (Ed.), Washington, D.C.

Rockström et al. (2010) Planetary boundaries: Exploring the safe operating space for humanity, Ecology and Society 14 (2): 32.

Rockström et al. (2009) A safe operating space for humanity, Nature, 461: 472-475.

Rogers. P and Ramirez-Vallejo, J. (2010), Failure of the virtual water argument? Paper presented at the "Water & Trade" Strategic Workshop held on 25-26 November 2010, European Science Foundation, Amsterdam, the Netherlands.

Rosegrant, M. W., Ringler, C. and Zhu, T. J. (2009) Water for agriculture: Maintaining food security under growing scarcity, Annual Review of Environment and Resources, 34: 205-222.

Tarasofsky, R. and Palmer, A. (2006) The two in crisis: Lessons learned from the Doha negotiations on the environment, International Affairs, 82: 899-+.

The Economist (2010, August 26) The miracle of the cerrado brazil has revolutionised its own farms. Can it do the same for others?, In: The Economist, Retrieved September 21, 2010, from www.economist.com/node/16886442.

Wichelns, D. (2004) The policy relevance of virtual water can be enhanced by considering comparative advantages. Agricultural Water Management, 66: 49-63.

Wichelns, D. (2010) Virtual water: A helpful perspective, but not a sufficient policy criterion, Water Resources Management, 24:2203-2219.

Yang, H., Wang, L. and Zehnder, A. J. B. (2007) Water scarcity and food trade in the southern and eastern Mediterranean countries, Food Policy, 32: 585-605.

Yang, H. and Zehnder, A. J. B. (2002) Water scarcity and food import: A case study for southern Mediterranean countries, World Development, 30: 1413-1430.

Yang, H., Reichert, Peter; Abbaspour, K.C. and Zehnder, A. J. B. (2003) A water resources threshold and its implications for food security, Swiss Federal Institute for Environmental Science and Technology (EAWAG), 37: 3048-3054.

Yang, H., Wang, L., Abbaspour, K.C. and Zehnder, A.J.B. (2006) Virtual water trade: An assessment of water use efficiency in the international food trade, Hydrology and Earth System Sciences, 10: 443-454.

You et al. (2010) What is the irrigation potential for Africa?, IFPRI, Washington, D.C. www.ifpri.org/sites/default/files/publications/ifpridp00993.pdf.

5. Constraints and opportunities in meeting the increasing use of water for energy production

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Abstract

Billions of people lack access to modern water and energy services. This fact, coupled with population growth and growing economies at the national and regional level, will mean that the demand for water and energy services will grow significantly over the coming decades. As societies look to meet this growing demand, there are new pressures to decarbonise the energy production chain and reduce greenhouse gas emissions. Water is required to produce energy and energy is necessary to manage water for different usages. The two assets are strongly linked and the provision of both is key to stimulate growth and improve livelihoods. This paper investigates whether and how the availability of water, which is needed for multiple human uses and ecosystems, can be a constraint to energy generation at different spatial scales. Water use trends for energy production from Europe, USA and the Middle East demonstrate the demand for water for this sector is increasing as societies develop and transform. Data on water withdrawals and use in the energy production chain for different sources of fuel and power production technologies are then compiled and analysed to indicate patterns in water consumption. The study concludes that joint water and energy assessments would improve future water and energy planning and enable the formulation of policy measures that are able to account for both assets in conjunction taking other water users into account.

Introduction – the linkage between water and energy

Water is required to produce energy, including for fuel production and power generation. Energy is needed to move and clean water in distribution and treatment systems (WEF, 2008). This link has been referred to as the "water and energy nexus". There is a growing recognition that improved understanding of how this nexus functions is important as it is integrated within the production of both tangible assets, such as clean water, power, and agriculture products, and also helps better the management of intangible assets, including public goods, such as maintaining and restoring ecosystem services through governance choices. Water resources management and development address several aspects of water in the hydrological cycle: green water (soil moisture); blue water (rivers, streams, lakes and groundwater); and grey water (through management of return flows of water used by industry and households) (UNESCO, 2009). Water is consumed for energy production; primary production; by industry and households; and for ecosystem services at the local and regional level (Philips et al., 2008). Both water and energy are in a state of flux and need to be managed, developed and delivered at different spatial scales demanding major investments in human and financial terms.

Power is required for water management and development. It is used for pumping, extraction, transfer and treatment of water for the delivery of irrigation of water for food and bioenergy production and for the construction of hydraulic infrastructure. As fresh water resources become scarce at the local, national and regional levels, water will be transferred, pumped long distances, or be produced through alternative means, such as energy intensive desalination processes and recycling (WEF, 2008). Modern water management, including establishing monitoring networks and data centres, is thus dependent on reliable access to electricity.

To achieve water security, which can be defined as "the provision of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production" (Grey and Sadoff, 2007), energy must be available for water management and development. Similarly, to achieve energy security, which can be defined as "the uninterrupted physical availability of energy at a price which is affordable, while respecting environment concerns" (IEA, 2011), water needs to be available for many steps in the energy production chain.

Current information on water use in the energy production chain at the local and regional scale is incomplete. In most fuel extraction and refinement processes, assessments of consumptive water use are not accounted for systematically, although they are included to some degree by the corporate sector. There is, however, an increasing number of research institutes undertaking research into methodologies that assess water withdrawal and usage in the energy production and power generation chains. Even if standardised methods to account for water consumption in various energy producing activities are still being developed, indications are that water may be a constraint in many parts of the world because of water quantity, availability and quality concerns.

This paper will highlight the growing demand trends for water and energy services at different spatial scales and illustrate water withdrawal and use in the energy production chain through a compilation of water use patterns for different energy technologies. It will then propose an analytical approach to analyse water and energy issues in conjunction.

Method

The analysis of drivers and trends in water and energy demand has been developed through a literature review of data from the International Energy Agency (IEA), which is an autonomous agency supporting the Organisation for Economic Co-operation and Development (OECD), the International Energy Outlook (IEO) prepared by the US Department of Energy, the Intergovernmental Panel on Climate Change (IPCC) and its working group III on mitigation of climate change and other referenced sources. The compilation of water use in the energy production supply chain is developed through a literature review. Data has been collected and compiled from a number of sources to provide a first level understanding of the role of water in this value chain. Water consumption values are presented in ranges and provide an indication of the real water consumptive patters in the energy production chain.

Global scenarios and trends of water and energy demand

Access to and exploitation of energy and water are necessary for social and economic development (GA, 2009; UN Water, 2009). IEA (2010 A) clearly demonstrates the links between increases in Human Development Index (HDI) and access to energy. With increasing populations, economic development, and changes in lifestyles, global demand for water and energy is increasing (WEF, 2011). UN DESA (2007) estimates that the global population will grow from 6.7 billion to 9.2 billion in 2050. This situation in parallel with raising economic standards will significantly increase the demand for water and energy services at the local, national and regional levels. The local, national and regional contexts will differ as political, social, and geographic features vary everywhere. This also means that best options for governance and management responses will not be the same in any two places. The following sections provide some information on the trends in demand and supply of water and energy in different regions.

Global trends in water use

According to the Comprehensive Assessment of Water Management in Agriculture (2007) a fifth of the world's population live in areas of physical water scarcity. The definition of water scarcity is a region where water resources development is "approaching or has exceeded sustainable limits" and "more than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes" (Ibid). These figures have been translated into services gaps of water and energy for people. The current aggregated global service gap in access to water is striking with estimates from the WHO and UNICEF (2010) stating that 2.6 billion people do not have access to improved sanitation facilities and 884 million people do not use improved sources of drinking water.

In parallel Vörösmarty et al. (2010), find that 80% of the world's population is exposed to high levels of threat to water security because of large scale transformation of water systems through land cover change, urbanisation, industrialisation and hydrologic infrastructure. The authors claim that major investments to reach water security in developed economies are masking the underlying causes for the threat to water security, while in developing economies the threat is much greater as there is little investment in water management and development (Ibid).

The future water use scenario data by McKinsey & Company (2009) indicates that by 2030, we will face a 40% global supply gap of accessible, reliable water supply for economic development. This figure is an aggregation of a very large number of local water gaps and refers to the quantity of accessible, reliable, environmentally sustainable supply, which is a much smaller quantity than the absolute raw water available in nature (Ibid).
Long term climate change, on top of existing rainfall variability, will provide additional water management challenges at the regional and local levels. Droughts and floods may increase in many regions and cause shocks to both developing and developed economies influencing water supply, demand and buffering systems (UN Water, 2009).

Global trends in energy consumption

Estimates by UN Energy (2011) and EIA (2010 A) are stating that 1,6 billion people lack access to electricity and a further 1,4 billion people lack access to modern fuel for cooking, lighting and heating. Global energy consumption is projected to grow by close to 49% from 2007 to 2035 according to the International Energy Outlook (IEO) 2010 reference case, prepared by the US Energy Information Administration (EIA). This estimate is similar to the projection made by the International Energy Agency (IEA) in its baseline scenario that estimates that primary energy use will rise by 84% until 2050 (IEA, 2010 B). Both these scenarios are based on a high dependence on fossil fuels, especially coal, and conclude that the "the largest projected increase in energy demand is for non-OECD economies" (IEO, 2010). Fossil fuels contribute 85% of the total global primary energy demand in 2008 (IPCC, 2011 A).

Alternative energy scenarios are developed in response to tackle the CO2 emissions from fossil fuel use. As energy production is responsible for 40% of greenhouse gas emissions, low-carbon energy growth scenarios have been developed, such as the IEA BLUE scenario (IEA, 2010 B). The IEA BLUE scenario includes a range of existing and new technologies that would decarbonise the power sector as well as other steps towards increasing energy efficiency in society. The IPCC Special Report on Renewable Energy Sources (2011) provides an overview of 164 low-carbon scenarios that are lumped into four groups of key scenarios. All low-carbon scenarios indicate a substantial increase in the deployment of Renewable Energy (RE) Technologies by 2030, 2050 and beyond (Ibid). The RE technologies assessed, include bioenergy, direct solar energy, hydropower, geothermal energy, ocean energy and wind energy. The first three technologies depend on reliable access to water resources in order to function. In 2008 these RE technologies accounted for roughly 13% of total primary energy supply (Ibid). All forecasts predict that renewable energy will take larger market shares. It is predicted that hydropower will take the largest share of this growth followed by wind power, with 54% and 26% respectively of the total incremental power supply (IEO, 2010).

Electricity production and demand

Electricity is the world's fastest-growing form of energy consumption for end use purposes according to the IEO projected reference case 2007 – 2035. Consumption is estimated to increase 87% by 2035 (ibid). Electricity is used to meet an increasing portion of the world's total energy demand and grows faster than liquid fuels, natural gas, and coal in all end-use sectors other than transportation. Net electricity generation worldwide is predicted to grow by 2.3% per year on average to 2035, faster than world energy demand, which is to grow 1.4% annually (Ibid).

Coal will continue to be the fuel used most for electric power production at the global level in the IEO 2010 and IEA (2010 B) baseline scenarios. In 2007, coal-fired generation accounted for 42% of world electricity supply and in 2035 its share is predicted to increase marginally to 43% (Ibid). One explanation for the development of coal fuelled generation is the attractiveness in cost compared to other sources, especially in coal rich countries such as China and India.

For all the world's regions, a mix of renewables, nuclear and fossil-fuels combined with carbon capture and storage technologies will be needed to meet the growing energy demand (IEA, 2010 B). The composition of that mix will depend on the degree of deployment of RE technologies. Different regions will have different endowments of energy resources to develop. Regardless, the choice of low-carbon technologies or fossil fuel rich power generation, water will be a key input to consider in future power planning exercises and likewise the use of water for energy production needs to be considered by water managers.

Illustrations of the changing patterns of water use at the regional level

An estimated 3,800 km^3 of freshwater is withdrawn annually, with 70% of the water used for irrigation, 20% for industry and 10% for municipalities (Comprehensive Assessment of Water Management in Agriculture, 2007). There are large variations, however, of water use in different regions of the world depending on climate, soils, population and economic pressures. Water withdrawal for cooling purposes during energy generation and for hydropower generation is growing rapidly (Ibid). Some of the water used this way is lost through evaporation or evapotranspiration and the rest is returned to the river basins. The water quality of the return flow of water used for cooling is often degraded because of increase in temperature and change in water quality compared to the intake water and this will have an impact on downstream users (Ibid).

Europe

In the European Union (EU) approximately 44% of water is used for energy production, 24% for agriculture, 17% for public water supply and 15% for industry (EC, 2007). These numbers do not take return flows into consideration. The deployment of new technology in power generation limits the consumptive water use to 5% of the abstracted water with potential further decreases the coming years (Ibid). In some EU countries, water abstraction for energy production equals more than 50% of total use. In Germany alone, this translates to 28.8 billion m^3 of water each year (Ibid). A growing portion of the EU territory is also affected by drought (Ibid).

Power producing plants in EU are vulnerable to water issues at the local level due to short term water scarcity and environmental regulations. Many of the nuclear power plants in France e.g. rely on freshwater resources and are located along rivers. France has periodically been forced to shut down several of its nuclear power plants during the last decade and import power from neighbouring countries due to temperature limits for the return flows and water shortages due to summer heat waves (IPS, 2005; The Times, 2009). Simultaneously, the EU has set ambitious targets to boost its bio fuel production to secure energy supplies (Bio fuels Research Advisory Council, 2006).

United States of America

The distribution of freshwater withdrawals in the United States of America is similar to the EU: Approximately 40% is used for irrigation, another 39% for thermoelectric generation, and the remaining 21% is divided between municipalities, industry, aquaculture and livestock (DOE, 2006). In the case of freshwater withdrawn for thermoelectric generation, 97% of the water is returned to the recipient with higher temperature and other changes in water quality (Ibid). In the case of irrigation, about 79% of the water withdrawn is lost from evapotranspiration and in conveyance (Ibid).

Thermal electric power generation in the US corresponds to 3.3% of the total fresh water consumption (DOE, 2006). This corresponded to 20% of the non-agricultural use of water consumption in 2006 (Ibid). Though only a small portion of the water withdrawn is consumed in the power production process water needs to be available constantly for cooling purposes. In addition, environmental impacts also need to be considered both when water is withdrawn and when water is returned into ecosystems with altered temperature and quality following its use during energy production processes (Ibid).

In addition to its substantial national coal and petroleum energy sector, the US Food and Agricultural Policy Research Institute (FAPRI, 2008) has projected that the production of ethanol will more than double by 2017 and the production of biodiesel will increase almost three times.

Middle East

Water resources are already under intense pressure in the Middle East region, and the demand for both water and energy continues with economic growth. The region has the highest per capita rates of freshwater extraction in the world and exploits over 75% of its renewable water resources. The agricultural sector consumes on average about 80% of the freshwater resources. Significant quantities of water are needed to extract and refine petroleum based fuels. Power is at the same time needed to extract water from increasingly more inaccessible aquifers, desalinate seawater and pump water long distances from remote sources to target areas, all of which constitute a substantial portion of regional energy consumption. In Jordan, roughly 15% of all electricity used in the country is consumed by the water authority. Oil exporting nations of the Middle East along the coastal zones are possibly better positioned to utilise desalinisation of sea water by using fossil fuels to generate the energy to power the process. While this is an avenue to increase supply of water resources, it poses local environmental risks related to discharge of brine to the sea water, and is a source of CO_2 emissions (Granit and Löfgren, 2009).

As these regional examples demonstrate, water use patterns are dependent on the area of analysis. Global statistics will not provide the detailed policy guidance needed to construct strategies to jointly address water and energy security issues. Data on energy and water demand needs to be disaggregated at the regional and local level and coupled with an analysis of the spatial distribution of water allocated to multiple uses, including energy production and the production of fuel for electricity production.

The next section will outline the water use in the energy production chain to provide a better understanding of the role of water in these processes.

The role of water use in the energy production chain

Can water become a constraint in energy production? To answer this question, one can begin with an analysis on each of the components of the energy production chain and how water is used at each link.

Water utilisation in the energy production chain

Much of the available information on water use throughout the energy production chain is not systematised and results vary depending on the methodology used. The large number of fuel extraction, processing, refining and power generating techniques available provide a wide range of water consumption and withdrawal patterns. However, ranges of water use for producing different sources of fuel and for power production technologies are available in the literature.

When assessing water use in the energy production chain it is important to make a distinction between water consumed and water withdrawn. The Water Footprint Network (2011) defines water withdrawal and consumption as follows: "Water consumption is the volume of freshwater used and then evaporated or incorporated into a product. It also includes water abstracted from surface or groundwater in a catchment and returned to another catchment or the sea (ibid)". "Water withdrawal is the volume of freshwater abstraction from surface or groundwater. Part of the freshwater withdrawal will evaporate, another part will return to the catchment where it was withdrawn and yet another part may return to another catchment or the sea (Ibid)".

Opposing perspectives on the extent to which water is "consumed" during its use for energy production, and in particular during its use for hydropower production, have resulted in a wide range of estimates on the topic. In the case of hydropower, different production technologies such as run-off-the-river plants use no or relatively small water reservoirs. When water is stored in reservoirs, however, some water will be consumed due to evaporation. How much water that is consumed depends on several factors, such as the surface area and depth of the reservoir and local climate conditions (Glennie et al., 2010). References on water consumption in hydropower production display the broadest range of consumptive values amongst the different power producing technologies presented in this paper varying from negligible amounts of water consumed to values above 200 m^3/MWh (IPCC, 2011F). Reservoirs for hydropower are often used for multiple purposes and consumption related to other uses is difficult to distinguish in the existing data. This means that the figures on consumptive water use for hydropower might be considerably less then what is often reported (Ibid).

Water use in the production of different sources of fuel (primary energy production)

<u>Coal</u>

Coal extraction and preparation use freshwater in various treatment steps. Water is used during surface- and deep coal mining, as well as the transport and storage process. More water is needed to prepare the raw product before transportation and in related processes such as dust management, drilling, and factory consumption. Approximately between 200- 300 l of water are used to process one tonne of coal (Evans et al., 2003). Water consumed throughout the coal production chain can be estimated to 2-12 m^3/TJ (Table 5.1).

Table 5.1. A compilation of estimates on water consumption of fuel extraction, processing and refinement. The range of estimates provides an overview of the general area of water consumption values. Based on Maheu et al., (2009), WEF (2008) and Younus et al. (2009).

Range of approximated water consumption in selected types of fuel production				
Oil	Coal	Bio fuel	Natural gas	Nuclear fuels
6-640 m^3/TJ (various types as specified by EIA , 2011)	2-12 m^3/TJ (various mining types)	9,000-100,000 m^3/TJ (corn)	Negligible (Shale gas 0,4-1 m^3/TJ)	Negligible-0,1m^3/TJ (Uranium- different extraction methods) 2-12m^3/TJ (Uranium processing steps)

Petroleum refining

Oil and natural gas production utilise water in similar ways in the extraction process. Small amounts of water are consumed during the extraction process. Withdrawn water is normally re-injected to abstraction wells during the process (EPA, 2010). Water is however consumed within the refinement process such as for desalting and alkylation sequences (Ibid). Considerable variations can be detected depending on the efficiency discrepancies of different techniques utilised. Values of water consumption in petroleum extracting and refining steps range between 6-640 m^3/TJ.

Bio-fuels

Bio-fuels are renewable fuels based on living organisms. Ethanol is the most common type of fuel based on feedstock from corn and sugarcane (Varghese, 2007). Bio-diesel is normally produced from vegetable oils based on feedstock such as palm, soybean, rapeseed, sunflower seed etc. and occasionally also from ethanol (Ibid). Bio-fuel represents about 1% of global crop water demand and about 1.67% of irrigated water use (Ibid). The bio-fuel sector has been growing exponentially the last decade (Ibid). Bio fuel production requires comparably large quantities of water, with variations depending on the type of feed- stock used. Water consumption in bio-fuel production from corn range between 9,000 - 100,000 m^3/TJ.

Nuclear fuels

Extraction and processing of uranium to be used in nuclear power generation consumes water in several stages. Water consumption depends for instance on type of mining techniques but this corresponds to a minor part of water consumption related to preparing uranium (Maheu et al., 2009). Different enrichment techniques use large quantities of water in the uranium processing chain and ranges vary between 2-12 m^3/TJ (Ibid).

Water use in electric power production

When a specific fuel type has been produced it can be used to produce electric power. Water is required in this process. The most common use of water in power generation is for cooling. The level of water consumption varies substantially depending on the source of energy and different cooling technologies used. Electricity produced from renewable energy sources, such as ocean and wind power, consumes negligible amounts of water, as do different types of hydropower and solar power. Table 5.2 provides an overview of water consumed in the power generation process for different technologies.

Thermoelectric power generation by fossil and nuclear fuels

The process of generating power through fossil fuels, such as coal and oil, involves the burning of fuels and converting them into electric power. Water is primarily used during the different cooling processes, and quantities vary depending on system used. Cooling techniques can be divided between “wet” and “dry” systems and by techniques, which include “once through”, cooling towers and cooling ponds (Glennie et al., 2010). Once through cooling demands more water but less is consumed than in cooling tower systems and ponds (Ibid). Thermoelectric generation through nuclear energy involves generating heat through sustained nuclear fission. Water usage patterns resemble those of fossil fuel based thermoelectricity with similar cooling techniques.

Table 5.2. Types of power generation methods with related assessed water consumption. Ranges consists of values related to different technologies within each power generating method, thus creating wide ranges in specific cases. Based on Glennie et al. (2010), Maheu et al. (2009), IPCC (2011 F) and WEF (2008).

Ranges of approximated water consumption in selected types of power generation					
Fossil fuels	Nuclear	Biopower	Hydropower	Wind, Ocean	Solar
Negligible- 4 m^3/MWh (fossil fuels- various cooling techniques)	1.5-3.3 m^3/MWh (various cooling techniques)	0.8-3.2 m^3/MWh (steam, biogas)	Negligible -100 m^3/ MWh (0-209 m^3/MWh is an IPCC estimate but with stated uncertainties)	Negligible	Negligible – 4.3 m^3/ MWh Photovoltaics low range values- (CSP) high range values

Biopower

Biomass is used for power production. Foremost lignocellulosic bio-mass from wood, straw and crops are converted into power through densification and combustion processes (IPCC, 2011 C). Power generation by biomass often allows for co-generation opportunities where excess heat from steam can be used in heat generating systems. Conventional solid biofuels normally have lower production costs than the liquid counterparts (Ibid). As for other thermal technologies, water consumption is tied to cooling processes and varies depending of the specific type utilised, with most water consumed in recirculating cooling systems (Ibid).

Hydropower

Hydropower is an energy source where power is harnessed by capitalising on the energy generated when water moves from higher to lower elevations (head). It constitutes slightly less than 20% of the global electricity supply, which makes it by far, the largest current producer of renewable power (IPCC, 2011 F). The technological maturity of the industry, comparably high conversion efficiency (90%) (Ibid) and the presence of untapped, existing potential sites for hydropower plants often make it a cost effective power generation option for many regions and the entire sector continues to develop rapidly. According to the IPCC (2011 D), the currently existing worldwide potential for hydropower generation is estimated at 14,576 TWh/year). The multitude of operational technologies, plant-scales and multiple purpose use opportunities of the water stored makes it difficult to provide average values of water consumed.

Ocean energy

Ocean energy refers to a number of ways of generating power from the ocean. Among established energy sources are: waves, tidal range, tidal currents, ocean currents, ocean thermal energy conversion and salinity gradients (IPCC, 2011 E). However, compared with other energy technologies there are few reliable assessments on the full potential of this type of energy. As power generating technologies for ocean energy are non-thermal, and unlike hydropower plants, does not store water, water consumption is considered to be minimal.

Wind energy

The wind energy sector is growing substantially. Current world wide electricity supply of slightly less than 2% from wind power could, in best case scenarios, grow to roughly 20% when utilising on- and off shore grid connected technology (IPCC, 2011 G). Many challenges, ranging from institutional, environmental and social issues, need to be addressed if the estimated worldwide technical potential of up to 125,000 TWh annually is to be realised (Ibid). Wind energy holds much promise when exploring options with regard to mitigating negative climate change impacts. As in the case of ocean energy, the technology utilised in wind power generation puts water consumptive values at negligible estimated values.

<u>Solar energy</u>

Solar energy has the potential to deliver a wide range of services through technology at different states of maturity. Electricity is generated in two ways: through direct conversion via photovoltaic (PV) cells or through Concentrated Solar Power (CSP) involving power plant processes. Despite substantial cost decreases over the last decades, both technologies are still not deemed to be fully competitive compared to conventional power producing methods (IPCC, 2011 B). Water consumption related to solar power is largely dependent on which generation technology and cooling processes that are involved. In general CSP consumes more water compared to PV cells (DOE, 2006).

Conclusion - assessing water and energy security in conjunction

Water resources and energy sources are unevenly distributed between countries and within regions. Strong demand drivers, as illustrated with global and regional examples, for energy and water services are present in an increasingly water resources and energy scarce world. Baseline projections of future energy demand show a close to 50% increase over the next 25 years. The baseline scenarios use significant amounts of conventional power technologies that consume and/or need a reliable water supply for cooling purposes. Alternative low-carbon scenarios also indicate strong demands for energy, albeit with a stronger focus on RE technologies to reduce the carbon footprint and to mitigate climate change. Many of the current RE technologies, as illustrated in the compilation of ranges of water use in the energy production chain, demonstrate a high demand for water (biopower, CSP, and hydropower depending on technology). It is therefore important to have a good understanding of the water consumption patterns for these RE technologies.

Despite the wide range of estimates created by the differing methods to classify water use in energy production, all evidence points to water as a vital component within the energy production chain. Different sources of fuel, as illustrated in Table 5.1, consume different amounts of water in the extraction and production process. Bio-fuels consume a comparably substantial quantity of water, while processing steps for coal and uranium usually consume less. In the power production stage the actual water consumption is less than the water withdrawn, as significant return flows send water with higher temperature and altered quality back to the recipient. Even if the actual consumption of water in power production is fairly low compared to other sectors, withdrawal figures are high. Consequently, water supply needs to be ensured to avoid disruptions to power production processes.

Water and energy service provision are linked and water and energy security issues must be analysed in conjunction at the appropriate spatial scale. A better understanding of the linkages between water use in society and for ecosystem services with energy production is therefore called for to avoid future supply bottlenecks and to provide all people with modern energy and water services. Such a strategic understanding should be built at the local, national and regional levels to ensure water and energy security. Global agreements to mitigate for climate change provide strategic guidance on climate change objectives and provide roadmaps for different energy technologies (see e.g. IEA, 2010 B) that can be adapted at different spatial scales.

Considering that water and energy assets are spatially unevenly distributed within countries and in regions, it is critical to have a good understanding of how the resources can be developed and how they can be integrated in a system planning approach that takes multiple users into account. Water, compared to energy, is not so easy to trade and reserves need to be kept to maintain ecosystem services and other critical uses including for primary production, industry and domestic use.

To improve local, national and regional energy and water planning, assessments are needed that indicate the estimated requirements for water from alternative options for energy production that can meet future demand taking other water users into account. These assessments should include separate estimates for the quantity of water that will be withdrawn and the volume of water that will be consumed or returned at a degraded quality at each stage of the energy production chain. Doing this would both require and help catalyse strong partnerships between water and energy governance authorities, and help guide both water and energy producers in their longer term policy planning at the appropriate scale. All regions with large suppressed demand for both water and energy, areas that anticipate steady economic growth, and areas that face growing water scarcity would benefit from such an integrated planning approach.

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References

Biofuels Research Advisory Council (2006) European commission directorate-general for research information and communication unit. Biofuels in the European Union a vision for 2030 and beyond. Reference No.: EUR 22066.

Comprehensive Assessment of Water Management in Agriculture (2007) Water for food, water for life: a comprehensive assessment of water management in agriculture. London: Earthscan, and Colombo: International Water Management Institute.

DOE [US Department of Energy] (2006) Energy demands on water resources. Report to Congress on the Interdependency of Energy and Water.

EC [European Commission] (2007) Water scarcity & droughts. In-depth assessment second interim report – June 2007. Version no.: 1.0. DG Environment.

EPA [United States Environmental Protection Agency] (2010) Water & energy efficiency by sectors. Retrieved February, 2011 from: www.epa.gov/region9/waterinfrastructure/oilrefineries.html

Evans, R., Roe, P. and Joy, J. (2003) Water use and sustainable development in coal mining – a case study from central Queensland. Modified paper presented at the minerals council of Australia's Sustainable Development 03 Conference, Brisbane, 2003.

FAPRI [Food and Agricultural Policy Research Institute] (2008) US and world agricultural outlook. Reference No.: FAPRI Staff Report 08-FSR 1 ISSN 1534-4533. Iowa State University, University of Missouri-Columbia Ames, Iowa USA.

GA [United Nations, General Assembly] (2009) Reliable and stable transit of energy and its role in ensuring sustainable development and international cooperation. 63/210, (United Nations A/RES/63/210).

Glennie, P., Lloyd, G.J. and Larsen, H. (2010) The water-energy nexus: the water demands of renewable and non-renewable electricity sources, DHI, November 2010.

Global Energy Network Institute (2002) Retrieved 8 April 2011, from www.geni.org/globalenergy/library/renewable-energy-resources/hydropower.shtml

Granit, J. and Löfgren, R. (ed.). (2010) Water and energy linkages in the Middle East – regional collaboration opportunities. Paper 16, SIWI, Stockholm, Sweden.

Grey, D. and Sadoff, C.W. (2007) Sink or swim? Water security for growth and development, in: *Water Policy* 9, (2007) 545–57, The International Bank for Reconstruction and Development/The World Bank.

IEA [International Energy Agency] (2010 A) Energy poverty how to make modern energy access universal? Special Early Excerpt of the World Energy Outlook 2010 for the UN General Assembly on the Millennium Development Goals, International Energy Agency. OECD/IEA.

IEA [International Energy Agency] (2010 B) Energy Technology Perspectives (ETP). Scenarios and Strategies to 2050. International Energy Agency, OECD/IEA.

IEA [International Energy Agency] (2011) International Energy Agency. Retrieved February, 2011 from: www.iea.org/subjectqueries/keyresult.asp?KEYWORD_ID=4103

IEO [International Energy Outlook] (2010) US Energy Information Administration (EIA), Office of Integrated Analysis and Forecasting US Department of Energy, Washington, DC.

IPCC [Intergovernmental Panel on Climate Change] (2011 A) Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate. Change Mitigation [O. Edenhofer, R. Pichs□Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T., Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [Intergovernmental Panel on Climate Change] (2011 B) Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Arvizu, D., P. Balaya, L. Cabeza, T. Hollands, A. Jäger-Waldau, M. Kondo, C. Konseibo, V.Meleshko, W. Stein, Y. Tamaura, H. Xu, R. Zilles, 2011: Direct Solar Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. v. Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [Intergovernmental Panel on Climate Change] (2011 C) Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Chum, H., A. Faaij, J. Moreira, G.

Berndes, P. Dhamija, H. Dong, B. Gabrielle, A. Goss Eng,W. Lucht, M. Mapako, O. Masera Cerutti, T. McIntyre, T. Minowa, K. Pingoud, 2011:Bioenergy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [Intergovernmental Panel on Climate Change] (2011 D) Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Kumar, A., T. Schei, A. Ahenkorah, R. Caceres Rodriguez, J.-M. Devernay, M. Freitas, D. Hall, Å. Killingtveit, Z. Liu, 2011: Hydropower. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [Intergovernmental Panel on Climate Change] (2011 E) Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate. Change Mitigation, Lewis, A., S. Estefen, J. Huckerby, W. Musial, T. Pontes, J. Torres-Martinez, 2011: Ocean Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [Intergovernmental Panel on Climate Change] (2011 F) Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate. Change Mitigation, Sathaye, J., O. Lucon, A. Rahman, J. Christensen, F. Denton, J. Fujino, G. Heath, S. Kadner, M. Mirza, H. Rudnick, A. Schlaepfer, A. Shmakin, 2011: Renewable Energy in the Context of Sustainable Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)] , Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC [Intergovernmental Panel on Climate Change] (2011 G) Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate. Change Mitigation, Wiser, R., Z. Yang, M. Hand, O. Hohmeyer, D. Infield, P. H. Jensen, V. Nikolaev, M. O'Malley, G. Sinden, A. Zervos, 2011: Wind Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)] , Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPS [Inter Press Service] (2005) Retrieved July 9, 2011 from: http://ipsnews.net/news.asp?idnews=29441

Maheu, A., Connor, R. and Mckeys R. (2009) Energy choices and their impacts on demand for water resources: an assessment of current and projected water consumption in global energy production, UNISFERA, McGill University.

McKinsey & Company (2009) Charting our water future – economic frameworks to inform decision making, 2030 Water Resources Group.

Phillips, D., Allan, A., Claassen, M., Granit, J., Jägerskog, A., Kistin, E., Patrick, M. and Turton, A. (2008) The TWO analysis: introducing a methodology for the transboundary waters opportunity analysis, SIWI Report no 23, SIWI, Stockholm.

The Times (2009) Retrieved February, 2011 from: http://business.timesonline.co.uk/tol/business/industry_sectors/utilities/article6626811.ece

UN DESA (2007) World population prospects. The 2006 revision. Executive Summary, United Nations, New York.

UN Energy (2011) Retrieved February, 2011from http://esa.un.org/un-energy/

UNESCO (2009) Integrated water resources management training programme for decision makers in the Middle East/ North Africa region.

United States Geological Survey (USGS) (2009). Estimated use of water in the United States 2005, US Department of the Interior, US Geological Survey, Reston, Virginia.

UN Water (2009) The United Nations World Water Development Report 3 – Water in a Changing World, Paris: UNESCO Publishing – London: Earthscan.

Varghese, S. (2007) Biofuels and global water challenges. Institute for Agriculture and Trade Policy (IATP), IATP Trade and Global Governance Program, Minneapolis, Minnesota.

Vörösmarty, C.J. McIntyre, P.B. , Gessner, M.O. , Dudgeon, D., Prusevich, A. , Green P. , Glidden, S. , Bunn S. E. , Sullivan, C.A., Reidy Liermann C., and Davies, P. M. (2010) Global threats to human water security and river biodiversity. Nature. Volume 467. Pages 555-561 (30 September 2010). Erratum November 2010.

Water Footprint Network (2011) Retrieved July 2011 from: www.waterfootprint.org/?page=files/Glossary

WEF [World Economic Forum] (2008) Energy Vision Update 2009. Thirsty Energy: Water and Energy in the 21st Century, World Economic Forum in partnership with Cambridge Energy Research Associates, Geneva, Switzerland.

WEF [World Economic Forum] (2011) Water Security – The Water-Food-Energy-Climate Nexus. World Economic Forum Water Initiative. Island Press. Washington/Covelo/London.

WHO and UNICEF (2010) Progress on sanitation and drinking-water: 2010 Update. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, WHO Press, World Health Organization,
Geneva, Switzerland.

Younos, T., Rachelle, H. and Poole H. (2009) Water dependency of energy production and power generation systems, VWRRC Special Report No. SR46-2009, Virginia Polytechnic Institute and State University Blacksburg, Virginia.

6. Alleviating water scarcity by optimizing "Green Virtual-Water": the case of Tunisia

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Abstract

The paper tries to analyse the general conditions for a possible optimisation of the most important terms of the overall water balance of Tunisia in order to make sustainable, in the long term, the exploitation of the available water resources and to guaranty the food security level associated with it. It appears that rain-fed agriculture represents an important mobilisation factor of "Green Water" resources and plays a key role in the food security. Nevertheless, the amount of "Green Virtual-Water" content of foodstuffs produced by rain-fed agriculture is not well known. One of the objectives of the paper is to evaluate the potential of "Green Virtual-Water" related to the two important rain-fed farming practiced in Tunisia, cereals and olive groves and to assess its variability. It appears that in general "Green Virtual-Water" corresponds to a large part of the overall water balance at the national scale and significant progress in controlling water scarcity can be achieved by improving the output of rain-fed agriculture and by optimizing "Virtual Water" trade balance.

Introduction

During the last five decades, Tunisia has been engaged in the development of its water resources in order to promote a modern and efficient agriculture and to support increased agricultural production. With its very limited resources, below the "severe water stress" threshold of 500 m^3/capita/year, Tunisia has succeeded in developing the irrigation sector. Nowadays, the development of water resources in Tunisia is reaching the ultimate water resource potential and the limit of water resource withdrawal has been clearly identified since the early 1990. From there, the principles of resource management have gradually evolved from a traditional approach based on water supply management toward new modes that target the water demand management. The authority has very soon implemented policies and has developed technical, institutional and economic instruments in order to improve and to optimise the water uses in the different socio-economic sectors, (Hamdane et al., 2007).

The idea, which largely prevailed during the last decades, is that irrigated agriculture is much more productive and profitable than rain-fed agriculture. Consequently, a very low interest has been devoted to the development of rain-fed agriculture. While the irrigated area has been increased by a factor of 7 over the last four decades, the area of rain-fed agriculture remained fairly stable, barely greater than before with a relatively low productivity. The central fact is that irrigation consumes a lot of water and its expansion is first and foremost limited by the availability of water and soil resources. At present, the agricultural sector is by far the largest consumer of water. The irrigation sector accounts for more than three quarters of the global water demand. It contributes to more than one third of the local agricultural production in value. This means also that almost two thirds of the agricultural production in value is provided by rain-fed agriculture

Rain-fed agriculture production is directly related to rainfall which is unevenly distributed in space and its availability is subjected to strong seasonal and inter annual variations. This corresponds to the so called "Green Virtual-Water" which refers to the total rainwater evaporation from the field during the growing period of the crop including transpiration by the plants and other forms of evaporation, Hoekstra and Chapagain (2008). The Virtual-Water content of a product is measured in (m^3/ton) at the place where the product is occurred (production-site definition).

In Tunisia, the amount of "Green Virtual-Water" put in rain-fed agriculture production is much more important than water used in irrigated agriculture. Rain-fed agriculture plays a key role in food security and takes an important part in Virtual Water trade (cereals, edible oils, etc.). Based on statistics on agricultural production and food products trade, one can evaluate the national water demand in Tunisia and draw up the national water balance. In an integrated approach which covers all forms of water resources and all water demands, the paper tries to analyse the general conditions for a possible optimisation of the most important terms of the water balance, namely "Blue Water", "Green Water" and "Virtual Water" in order to make sustainable, in the long term, the allocation and the use of the available scarce water resources and to guaranty the food security level associated with it.

Water resource development and management in Tunisia

Tunisia has a Mediterranean climate in the North and a Saharan one in the South. The average annual rainfall is around 220 mm, representing the equivalent of 36 km^3/year of precipitation throughout the country. These averages mask huge disparities; first as regards to the spatial heterogeneity where the average annual rainfall varies between more than 1000 mm in the North West and less than 100 mm in the South (Figure 6.1). Second as regards to the temporal variability: rainfall is observed with a minimum that may reach two thirds the average value and a maximum that goes up to 1.75 the average value.

Tunisia has developed most of its “Blue Water” resources by the way of a large water infrastructure (dams, hydraulic managements infrastructure, transfer networks, wells etc.). The total "Blue Water" potential is estimated on average at 4.8 km^3/year: 2.7 km^3/year are related to the total surface water and 2.1 km^3/year represent the total groundwater resources.

Irrigation has developed over more than 400000 ha (around 8% of the total agricultural area). With this potential, the irrigated area provides 35% of agricultural production in value and contributes to 25% of agricultural products exports. Foodstuffs products exports coming from irrigated agriculture are mainly citrus fruits and dates. These crops occupy 10% of the country’s irrigated area and consume 25% of the water used by the agricultural sector. But the limited water resources may make unsustainable and unfair the corresponding food trade in terms of "Virtual Water".

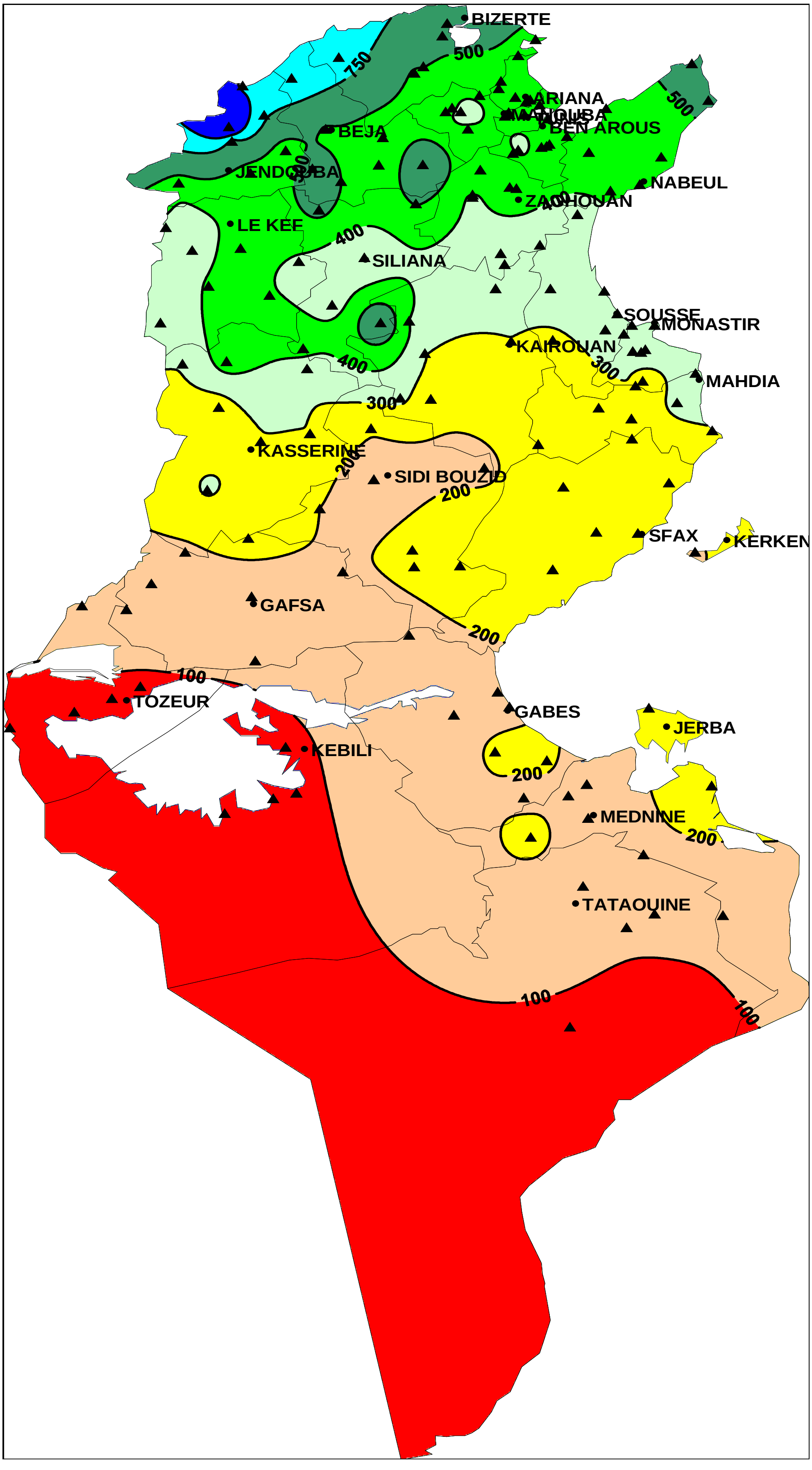

Figure 6.1. Tunisia: Administrative regions and average isohyets [mm/year] (Frigui, 2005).

Generally speaking, the total available resources resulting from surface and groundwater flows "Blue Water", represents a relatively small part (about one quarter) of total water resources of the country. "Green Virtual-Water" represents the stock of soil water available for crops that grow on harvested and non-harvested areas: cropland (4.5 Million ha), rangeland (4.5 Million ha) and forests (0.8 Million ha). The rain-fed agriculture plays an essential role in food security; in value, rain-fed agriculture represents, in an average hydrologic year, 65% of the national agricultural production and 75% of the agricultural exports.

Rain-fed agriculture represents the most important mobilisation factor of "Green Virtual-Water" resources and still offers large opportunities for development, intensification and increasing productivity. Nevertheless, the amount of "Green Virtual-Water" content of foodstuffs produced by rain-fed agriculture is not well evaluated. One of the prior steps to the development of these water and soil resources is the elaboration of accurate methods for the identification and estimation of their potential, their spatial distribution, their variability and their role in the global foodstuffs balance. This applies also to the "Virtual Water" flows associated with foodstuffs international trade, especially since a significant proportion of foodstuffs exchanges comes from rain-fed agriculture. In the following, we develop a method of systematic assessment of water resources involved in the production of rain-fed crops. This method is applied to cereals and olive trees farming in Tunisia and is interested in the evaluation of the mean amount of "Green Virtual-Water" resources as well as its variation.

Rain-fed agriculture and "Green Virtual-Water" assessment

Rain-fed agriculture of Tunisia

In Tunisia, rain-fed agriculture covers nearly 4.5 Million hectares, mainly used for cereal crops and olive trees. These two dominant rain-fed cropping systems occupy more than two thirds of the rain-fed agricultural lands on various soils and climatic conditions. Rainfall in Tunisia presents a very important contrast between the northern and southern regions and rain-fed agriculture has accommodated with these contrasting rainfall conditions. The Northern regions, where rainfall exceeds 500 mm/year, represent the major areas of cereal farming, while the centre of the country, where rainfall is much lower and more variable, is typically devoted to olive tree plantation. Both are mostly grown under rain-fed conditions and their productions are submitted to strong inter-annual variations.

The tests conducted on wheat crops over a period of seven years, in five different bioclimatic sites in Tunisia under rain-fed and irrigated conditions indicate that the grains yields are linearly correlated with the net water consumption measured on the field, (Rezgui et al., 2005). These experimental results suggest that a minimum water consumption ensuring grain production exists and, on all sites, its value is around 210 mm/year.

Based on these experimental agronomic results, an assessment model of "Virtual Green Water" content of rain-fed agriculture has been developed. The basic assumption of the model is simple: we assume that there is a linear relationship between the cereal production and the rainfall accumulation during the production cycle.

Analysis of "Green Virtual-Water" content of rain-fed agriculture

According to Rezgui et al. (2005) the amount of "Green Virtual-Water" $GW(i,n)$ in m^3, involved in rain-fed production of the year (n) in the region (i), is assumed to be proportional to the production and that it is proportional to the cultivated areas $S_G(i,n)$ expressed in hectares (ha), so that we can write:

$$GW(i,n) = 1000\zeta(i)Y_G(i,n)S_G(i,n) \quad (1)$$

where $\zeta(i)$ is the "Green Virtual-Water" content of the agricultural product in the region (i) expressed as a specific volume [m^3/kg] and $Y_G(i,n)$ the yield of the year (n) expressed in tons per hectare [ton/ha]. Related to cultivated areas, the volume of "Green Virtual-Water" can be expressed as a water height ($h_G(i,n)$ in mm) and applied to the area $S_G(i,n)$. Therefore, $h_G(i,n)$ represents the part of rainfall (in mm) effectively used by crops.

In order to consider the biannual alternate-bearing cycle especially that which characterises olive trees productions. We consider in general, that the two successive years are involved in the production of the year (n) with two respective weights α and β so that $\alpha + \beta = 1$. For cereals, the cycle of cereals crops is entirely covered by the hydrological year, which begins in September. It follows in this case that $\alpha = 1$ and $\beta = 0$. In return, the olive trees production cycle covers two successive hydrological years: part of the current hydrological year considered as the production year and part of the preceding year.

The "Green Virtual Water" involved in the rain-fed crops production is expressed as a function of rainfall in the general form:

$$h_G(i,n) = h_W(i,n) - h_S(i) = 100\zeta(i)Y_G(i,n) \quad (2)$$

where $h_W(i,n) = \alpha h_p(i,n) + \beta h_p(i,n-1)$, $h_p(i,n)$ is the rainfall height of the year (n) expressed in mm.

We consider in equation (2) that there is a threshold of water consumption, $h_S(i)$ expressed in mm, from which the production of grains is made possible. Under the threshold value we consider that crops production is zero. Equation (2) is a statistically linear relationship between rainfall and the water height that represents the "Green Virtual-Water" content of rain-fed crops production. Therefore, it should satisfy the following condition:

$$\forall \quad h_W(i,n) - h_S(i,n) > 0, \quad h_G(i,n) = h_W(i,n) - h_S(i) \quad and \quad h_G(i,n) = 0 \quad if \ not \quad (3)$$

One can also expect, at the national scale, similar linear relationships that link average rainfall and cereals crops yields. The amount of rainwater involved in rain-fed agriculture production of the year (n) throughout the country is written as the sum of the contributions of all the regions:

$$GW(n) = \sum_i GW(i,n) = \sum_i h_G(i,n)S_G(i,n) \quad (4)$$

Assuming that the "Green Virtual-Water" content $\zeta(i)$ is independent from the regional repartition and production of rain-fed farming so that it is identified with its spatial average value $\overline{\zeta}$, one may write the inter-annual average at the national scale as:

$$\overline{\zeta} < \overline{Y_G} >= \frac{1}{100}(< \overline{h_w} > - \overline{h_S}) \quad (5)$$

$$< \overline{h_G} >= (< \overline{h_w} > - \overline{h_S}) \quad (6)$$

Where $\overline{}$ and < > denote respectively the spatial and temporal averaging operators so that we have $< \overline{Y_G} >=< \sum_i Y_G(i,n) s_G(i) >$, $< \overline{h_W} >= \sum_i h_W(i,n) s_G(i)$ and $\overline{h_S} = \sum_i h_S(i) s_G(i)$. $s_G(i)$ representing the part of the rain-fed crops area cultivated in the region (i). We admit that this part varies slightly in time so that we can identify it to its average value: $s_G(i) =< \frac{S_G(i,n)}{\sum_i S_G(i,n)} >$

Assessing "Green Virtual-Water" content of the Tunisian rain-fed agriculture

The nationwide averaging is expressed as a linear combination of $< h_w(i) >$ and $< h_S(i) >$ both are weighted by the average regional rain-fed area. Figures 6.2 and 6.3 show the yields, at the national scale of cereals farming and olive tree groves as a function of the annual rainfall of the years 1998-2007. For cereals farming, the coefficient α is set equal to *1* assuming the cropping cycle lays within the hydrological year; while for olive tree farming, the annual rainfall is related to the year of olive production with coefficient alpha and to the precedent year with coefficient $(1-\alpha)$. The adjustment of the coefficient α indicates that the better correlation is obtained for the value $\alpha = 0{,}35$ suggesting that, in average, the hydrological year of olive production contributes to about one third in feeding olive trees while the preceding year contributes for almost two thirds.

On national average, the "Green Virtual-Water" potential related to cereal crops production represents a water height of 204 mm (e.g. 2040 m^3/ha). Applied to the average cultivated area (around 1,450 million ha between 2002 and 2007), one may estimate the average "Green Virtual-Water" to almost 3 km^3 per year. It is interesting to note that cereals production depends not only on rainfall; it also depends on the sown areas which is subjected to significant variations. If we apply the "Green Virtual-Water" height to the total cultivated area during 2004 (1,643 million ha), which corresponds to the maximum area sown between 2002 and 2007, one can estimate the average "Green Virtual-Water" potential of the Tunisian cereals agriculture at around 3.4 km^3 per year.

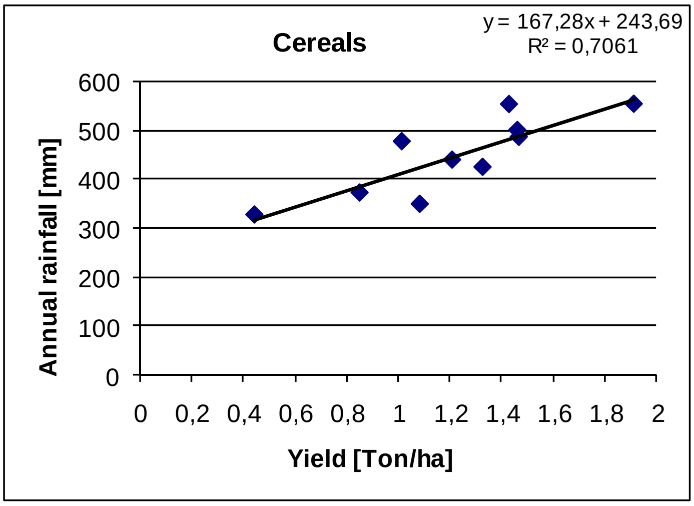

Figure 6.2. Cereals crops yields and Average annual rainfall (data MARH-1998-2007).

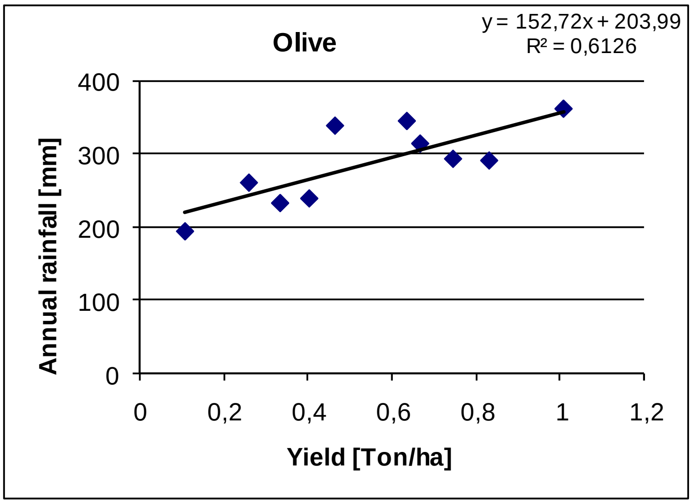

Figure 6.3. Olive trees yields and Average annual rainfall (data MARH -1998-2007).

The average "Green Virtual-Water" content of olive trees production devoted to olive oil production is estimated at about 1.15 km^3. This represents around 20 m^3 per olive tree in average throughout the country. Applied to the area of Tunisian olive groves for oil production estimated at around 1.35 10^6 ha, the amount of "Green Virtual-Water" corresponds to a water height of around 84 mm. This water height, applied to the total area of Tunisian olive groves estimated at the 1,540 million ha, gives a potential of the Tunisian olive groves at around 1.3 km^3 per year. There is no specific literatures that allow some systematic comparison but we can make some crosschecking with Spanish data. Aldaya et al. (2010) estimate the total Green-Water involved in Spanish olive sector to approximately 2 km^3 for a total olive groves area of 2.3 10^6 ha ; more than 80% of which are rain-fed. For irrigated crops, the authors distinguish between the water used in the production of a given crop proceeds from rainwater stored in the soil as soil moisture "Green Virtual-Water" or from surface or ground water "Blue Water". Reported to the total cultivated area, the amount of Green Water represents water height of 87 mm, slightly higher than the values given by the present study. Nevertheless, as Spanish olive groves has relatively high plantation density, typically 100 trees/ha, at least twice as dense as in Tunisia, (Galán et al., 2008), the amount of Green-Water per olive tree is much less important, nearly 9 m^3/olive tree.

Olive groves and cereals farming represent about 70% of the total rain-fed agricultural area in Tunisia. So we may estimate the total "Green Virtual-Water" potential of the rain-fed agriculture at around 6.6 km^3. These results are summarised in Table 6.1.

Table 6.1. Potential of "Green Virtual-Water" content of rain-fed agriculture in Tunisia.

	Weighted Rainfall $<\overline{h_w}>$ [mm]	Water threshold $\overline{h_S}$ [mm]	Virtual Water Content $\overline{\zeta}$ [m^3/kg]	Green Water height $<\overline{h_G}>$ [mm]	Rain-fed Area potential [10^6 ha]	Green-Water Potential [10^9 m^3]
Cereals	448	244	1.67	204	1.64	3.4
Olive	287	204	1.53	84	1.54	1.3
Rain-fed crops	(Total)				4.5	6.6

Sources: MARH, FAOSTAT

The two parameters $\overline{\zeta}$ and $\overline{h_S}$ obtained from the correlations between the rainfall and the rain-fed production (Figures 6.2 and 6.3) allow the computation of the "Green Virtual-Water" content according to one of the two following equations: $GW_1 = 10\,(<\overline{h_w}> - \overline{h_S}) < S >$ and $GW_2 = 1000\,\overline{\zeta} < \overline{R_G} >< S >$. The first equation has been used in the computation of the "Green Virtual-Water" potential of the rain-fed agriculture (Table 6.1).

Table 6.2. Average "Green Virtual-Water" content of cereals and olive farming productions in Tunisia.

	Average cultivated area [10^6 ha]	Average Production [10^3 Ton]	Green Water height $<\overline{h_V}>$ [mm]	Equivalent water per Kg $\overline{\zeta}$ [m^3/kg]	Average Green-Water GW_1 [10^9 m^3]	Average Green-Water GW_2 [10^9 m^3]
Cereals	1.64	1750	204	1.67	2.965	2.928
Olive	1.54	754	84	1.53	1.150	1.167

Data sources: MARH, FAOSTAT

Table 6.2 shows a comparison of the "Green Virtual-Water" Content related to rain-fed cereals and olive production computed according to two equations for the period 1998-2007. We verify that the two equations give quite similar average results. It should be observed, however, that this comparison does not constitute a validation of the model because the parameters $\overline{\zeta}$ and $\overline{h_S}$ has already been estimated from the statistics of the rain-fed farming production. Nevertheless this verification of the consistency of the assessment is very useful for studying the variability of the "Green Virtual-Water". The variability of cereals production depends also on the variability of sown areas which has obvious consequences on "Green Virtual-Water" assessments. Based on the statistics of rain-fed agriculture production, one may calculate not only the average value of "Green Virtual-Water resource", but also its standard deviation and therefore it becomes possible to associate frequencies of occurrence to high and low values. The results of this analysis are presented in Table 6.3.

Table 6.3. Variability of "Green Virtual-Water" of rain-fed agriculture in Tunisia.

	Green Water height $<\overline{h_G}>$ [mm]	Standard deviation of $<\overline{h_G}>$ [mm]	Green-Water Potential [Billion m^3]			
			Frequency 20% High - Low	Frequency 10% High - Low	Frequency 5% High - Low	Frequency 2% High - Low
Cereals	204	67	4.4 - 2.4	4.8 - 2.0	5.2 - 1.6	5.7 - 1.1
Olive	84	43	1.9 - 0.7	2.2 - 0.4	2.4 - 0.2	2.7 - - -
Rain-fed crops	(Total)		8.9 - 4.4	9.9 - 3.4	10.8 - 2.5	11.9 - 1.6

Data sources: MARH, FAOSTAT

"Green Virtual-Water" trade balance

The direct water demand (urban, tourism, industry) remains moderate (50 m^3/capita/year), In return, the amount of water required for food production is very high; estimated at around 1450 m^3/capita/year in 2004 (Besbes et al., 2010). About the third of this water demand is provided by foodstuffs imports (mainly cereals and vegetable oils) in the form of "Virtual Water". Rain-fed agriculture develops a significant part of the water resources providing more than the half of the equivalent water required for food needs. The contribution of the irrigated agricultural to the equivalent water of the food demand is thus about one sixth, (Chahed et al., 2007).

The analysis of the trade balance of cereals and edible oils between 1998 and 2007, helps make clear the role of rain-fed agriculture and thus the role of "Green Virtual-Water" in food security. Table 6.4 shows that the value of olive oil exports allows the covering of cereals imports value over the same period. Expressed in term of water equivalent, the trade balance related to olive oil export - cereals import represents however, a deficit of 2.2 km^3, a ratio largely below 1/3. In total, the water equivalent balance associated with cereals and edible oils represents an average deficit of around 3.8 km^3. This represents a considerable contribution which ensures the deficit in local production especially during droughts episodes.

Table 6.4. Average "Green Virtual-Water" trade balance.

		Average amount [10^3 Ton]	Average Value [Million $]	Equivalent water per Kg [m^3/Kg]	Equivalent water [km^3]	Specific value Price (2007) [$/ m^3]
Imports	Cereals	1842	307	1.67	3.1	0.100
	Edible oils	224	131	7.11	1.6	0.082
	Total		438		4.7	0.093
Exports	Olive oil	133	339	7.11	0.9	0.358

Data sources: MARH, FAOSTAT

The water balance is strongly in favour of Tunisia: The coverage rate of the trade balance of cereals and edible oils, which exceeds an average of more than 75% in value, represents less than 20% in terms of equivalent water, almost a factor one by four in value per m^3. This analysis in terms of water equivalent of cereals and edible oils trade highlights the essential role of rain-fed agriculture in basic foodstuffs trade balance: firstly, production of rain-fed agriculture represents a significant part of food exports; on the other hand, imports of basic foodstuffs (cereals and edible oils), which constitute an important item of food imports, are intended to cover the shortfall in local production mainly grown in rain-fed conditions.

The fact remains that, the performance of rain-fed agriculture is basically variable and, as shown before, there is a clear correlation between the crops yield and rainfall conditions. The effect of drought on the trade balance is considerable. The import of basic foodstuffs (cereals, edible oils etc.) increases significantly during droughts episodes. At the same time, the advent of drought weighs heavily on the food trade balance especially because its direct impact on rain-fed agriculture production. Based on the "Green Virtual-Water" values computed in Table 6.3, one can assign a monetary value to rain-fed agriculture and associate frequencies of occurrence to its high and low values. The results are shown in Table 6.5.

Table 6.5. Variability of "Green Virtual-Water" of rain-fed agriculture in Tunisia.

	Green Water potential [km^3]	Average Value [Million $]	Value of Green-Water Potential [Million $]			
			Frequency 20% High - Low	Frequency 10% High - Low	Frequency 5% High - Low	Frequency 2% High - Low
Cereals	3,4	340	440 - 240	480 - 200	520 - 160	570 - 110
Olive tree	1,3	465	679 - 250	786 - 143	858 - 72	964 - - -

Data sources: MARH, FAOSTAT

The analysis of the financial aspects associated with foodstuffs trade is of a great importance. The economic performance of the Tunisian foodstuffs trade balance was made possible in part because the price of cereals which remained relatively low and stable for a long period of time. The International cereal prices have remained low because of state subsidies to the agricultural sector in most producing countries. However, the recent increases in prices of basic food products (cereals, rice, vegetable oil etc.) show that the situation can change and strongly influence global food trade balances. The new context has revived the debate on the sensitive issue of food security in importing countries. This situation challenges traditional patterns of agricultural development and food security and should question a number of established concepts. The example of Tunisia shows very well how "Blue Water", "Green Water" and "Virtual Water" are linked together to form the entire water cycle at the national level. This general analysis becomes relevant particularly in countries with limited water resources.

A global water vision to improve the food trade balance

In the context when, as for Tunisia, the water availability becomes a limiting factor because of the resource potential, the water demand for irrigation must be satisfied with the water availability once the direct demand is covered. Indeed, the direct water demands for urban, industrial touristic sectors have an obvious priority in the resource allocation. In these conditions, the comprehensive water balance model constructed by Chahed et al. (2007) expresses, in these conditions, the Tunisian food water equivalent balance.

$$IW = EWR - (1 - RI)\ DD \qquad (7)$$

$$VW = FDWE - GW - k[EWR + (1 - RI)\ DD] \qquad (8)$$

The virtual water (VW) related to foodstuffs international trade corresponds to the difference between the total water equivalent of food needs (FDWE) and that of the local foodstuffs production: the water equivalent of the rain-fed agricultural production (green water GW) together with the water equivalent of the irrigated agricultural (IW). The equivalent water of irrigated agricultural is computed using an irrigation factor (k) that converts irrigation volumes (IW) into the equivalent water of the irrigated food production; this factor integrates irrigation efficiency and rainfall contribution. According to equation (1), the water demand for irrigation (IW) corresponds to the water available amount once the direct demand is covered. This corresponds to the difference between the exploitable water resource (EWR) and the direct water demand (DD). The direct water demand is supposed to be recycled into irrigation with a recycling index (RI). The verification of this model consists of testing a certain number of values of the parameters k (the irrigation efficiency factor) and RI (the recycling index for the direct demand), while providing the data concerning EWR (exploitable water resource), DD (direct demand), and FDWE (food demand water equivalent), and calculating the reference variable, VW (virtual water volume). This verification has been completed for the two years 1999 and 2004 (see Table 6.6).

The simplified formulation of the water balance (Eq. 7 and 8) is useful for simulating the future of water resource management and exploitation in order to prospect different scenarios at the national level. Two scenarios have been considered: The first one called "trend scenario" is based on the analysis of the actual trends in water management. It is based on a classic vision of water resources planning which considers only "Blue Water" and tries to match the available resource with the water demand. In recent decades the rain-fed cultivated lands have not really evolved and this scenario will extend these trends considering that the contribution of "Green Water" to the overall water balance will remain constant.

The second scenario, called "sustainable scenario" is more conceptual in that stems from a vision of what we want to see happen in the future in order to ensure sustainable management of all water resources. The sustainable scenario attempts to build a new water vision, at least in regard to agricultural sector by strengthening agricultural production taking advantage of all water and soil resources. This implies that efforts will be made to support rain-fed agriculture production by developing cultivated areas and by improving crops productivities so that, in average year, the "Green Virtual-Water" related to rain-fed agriculture production will be increased by 25% by 2030. The two of the scenarios assume that water needs will increase reasonably: the direct water demand will reach 70 m^3/capita/year by 2030 and the diet will be improved so that the water equivalent of the food demand is expected to reach 1700 m^3/capita/year for the same period. On the other hand the two of scenarios suppose the continuation and the amplification of the efforts made in recent decades to ensure water resource conservation and to enhance wastewater reuse. The scenarios admit that the rate of water recycling will reach a maximum of 50% by 2030.

Table 6.6. Adjustment and prospecting scenarios of the global water balance of Tunisia.

	2004	2008	Trend Scenario	Sustainable Scenario
Population [10^6 habitants]	9.1	9.93	12.70	12.70
Exploitable Resource (EWR) [$10^6 m^3$/year]	2380	2500	2700	2700
Food demand, Eq. water [m^3/year/Capita]	1350	1450	1700	1700
Total food demand (FD) Eq. water [$10^6 m^3$/year]	12285	14399	21590	21590
Direct water demand [m^3/year/Capita]	45	55	70	70
Total direct water demand (DD) [$10^6 m^3$/year]	410	546	889	889
Reuse rate, RI	0.08	0.1	0.5	0.5
Total irrigation allocation (IW) [$10^6 m^3$/year]	2003	2008	2256	2256
Rainfed agriculture (GW) Eq. water [$10^6 m^3$/year]	6500	8000	8000	10000
Conversion factor, k	0.9	0.9	0.9	0.9
Deficit of food balance (VW) Eq. water [$10^6 m^3$/year]	3982	4591	11560	9560
Total water demand	12695	14945	22479	22479
Rate of dependency	31%	31%	51%	43%

According to the first simulation (trend scenario), the continuation of the current trend until 2030 will have significant effects on the "Virtual Water" related to foodstuffs trade balance. The virtual water required to cover the deficit of the foodstuffs trade balance will increase from 4.5 to 8.5 km^3. Correlatively, the water dependency index, which is 31% in 2004 will reach 51% in 2030 (Table 6.6). In the second simulation for 2030, the productivity of rain-fed agriculture is expected to have a strong growth so that the amount of "Green Virtual-Water" related to rain-fed agriculture will rise by 25%. This would maintain the import of virtual water to a level more favourable than the first scenario, 43%.

Based on these results, we will analyse more formally the essential parameters that control the evolution of "Virtual Water" imports. The variation of the deficit of Virtual Water resource may be written as:

$$\Delta(VW) = \Delta(FDWE - GW - kIW) \quad (9)$$

At the short term, the deficit is essentially related to the annual variation of the production of the rain-fed agriculture. The equivalent water of foodstuffs demand is, at this scale almost stable, and the contribution of the irrigated agriculture, varies slightly due to the regulation of water supply systems. We thus may write:

$$\Delta(VW) = -\Delta GW \quad (10)$$

Which signifies that the variation of the deficit of the equivalent water of the food demand is mainly correlated to the variation of the output of the rain-fed agriculture. As shown in Table 6.3, the variability of the rain-fed agriculture production is significant and its impacts on food production are crucial. The deficit due to inter-annual variability can also be filled by the inter-annual national regulation using food reserves. This means that part of the strategies in developing the rain-fed agriculture lays in the management of its production: Stocking, distribution, trade. In connection with climate change issue, the inter-annual variability of rainfall is also an important concern. The perspective of rainfall reduction will have direct evident effect on the potentiality of rain-fed agriculture (Besbes et al., 2010); in return the effect of the amplification of rainfall variability on the amount of Green Virtual-Water content of rain-fed agriculture is less obvious.

At the long term, the overall water balance shows that the evolution of the "Virtual Water" deficit will follow the evolution of the foodstuffs consumption. As the "Blue Water" exploitable resource stabilises, the direct water demand (drinking water, industry) being incompressible and will increases with the population, the blue water agricultural allowances, (blue water) used in irrigation, should necessarily decrease. A realistic solution, but nevertheless ambitious at the long term, could be to stabilise the irrigated surface on a level such as the increase in the efficiency of the agricultural water use could compensate for the reduction of the agriculture water allocation. This means that the Equivalent-Water of the irrigated sector production will be stabilised, so that:

$$k\ IW = k[EWR - (1 - RI)\ DD] = Const \tag{11}$$

Thus the variation of the virtual water writes

$$\Delta(VW) = \Delta(FDWE - GW) \tag{12}$$

Equation (12) indicates that the evolution of the "Virtual Water" contribution will first depend on the evolution of the foodstuffs consumption. As the population increases the Virtual Water deficit will accordingly be amplified. The irrigation sector is constrained by the water availability; thus, the control of the increase in the Equivalent-Water of the foodstuffs imports lays in the improvement of the contribution of the rain-fed agriculture.

Defining the "Water Dependency Index" as the ratio of the "Virtual Water" deficit by the total food demand ($WDI = \frac{VW}{FDWE}$), one may calculate the variation of this index by:

$$\Delta WDI = -\Delta(\frac{GW}{FDWE}) = \frac{GW}{FDWE}\left[\frac{\Delta(FDWE)}{FDWE} - \frac{\Delta(GW)}{GW}\right] \tag{13}$$

The interpretation of this equation is indicative of the importance of the interest that should be bought to "Green Virtual-Water" resources associated with the output of the rain-fed agriculture: it indicates that the relative increase of the "Water Dependency Index" of the country is directly correlated to the relative increase of the equivalent water of food demand. Conversely, equation (13) shows that it is possible to maintain the value of the index at its initial level if the relative growth of the performance of the rain-fed agriculture, in terms of water equivalent of its production, follows the relative increase of the equivalent water food demand. Moreover, this index can be lowered if, in term of water equivalent, the relative increase of the rain-fed agriculture production exceeds the relative increase of food demand. Better yet, the budget of food trade balance may positively improve by benefiting of comparative advantage associated with the exchange of "Green Virtual-Water".

The water situation in Tunisia is such that it becomes increasingly difficult to continue the development of large-scale irrigated agriculture without consequences on the sustainability of the water and soil resources. This perspective leads to the obvious conclusion that now, Tunisia has to rely on all of its resources to develop and support its agricultural development efforts. In particular, it appears that the developing rain-fed agriculture is possible and its impact on water security is fundamental. This requires that we have to give to the rain-fed agriculture the same level of interest that has been given to the development of the irrigation, over the past four decades.

Conclusion

The current situation in Tunisia is characterised by a concrete limitation of the development of conventional water resources and an expected increase in the water demand of the different socio- economic sectors. This poses new challenges for irrigated agriculture in Tunisia which in this context should improve its productivity by improving the efficiency of the water uses. On the other hand, the production of rain-fed agriculture accounts for a significant part of exports of foodstuffs products, in particular, Tunisia exports large quantities of olive oil coming from rain-fed olive groves. The imports of cereals and edible oils are necessary in order to cover the deficit in the local agriculture production whose performance is highly dependent on climatic conditions because, for their major part, these foodstuffs are produced by rain-fed agriculture. Tunisia has also an interest in importing agricultural products of high water consumption, and at the same time in exporting agricultural products with low water consumption and high added value. According to this view point, rain-fed agriculture, without consequences on water resources, provides the largest part of foodstuffs production and plays an important role in the equilibrium of the food-stuffs trade balance. This approach, accounting for the impact of foodstuffs trade on water resource use, leads to better managing water resources exploitation avoiding the risk of its degradation.

Systematic "Green Water" development requires, the same way as conventional water resources, a careful assessment of its potential, a description of its spatial distribution and a characterisation of its temporal variability. The objective is to make this water potential more visible and more concrete in order to integrate it systematically into the prospects for development and exploitation of water and soil resources. The "Green Virtual-Water" assessment at the national level, presented in this paper follows this approach and we develop in on-going research regional analysis of this important resource.

As in Tunisia, the objectives of food security in water scarce countries should consider all of the contributions of water and soil resources that participate to food production. The integration of all water resources at the national scale, including the "Green Virtual-Water" content of rain-fed agriculture and of foodstuffs trade balance, is essential in facing the great challenges of food security in arid countries. The development of rain-fed agriculture should be regarded as a mode of development of water and soil resources for which appropriate solutions have to be developed. The main objective is to make rain-fed farming viable and profitable in order to further expand its production and consolidate its economic and social roles. These objectives require structural solutions in order to develop rain-fed agriculture (extend of rain-fed farming, development of foodstuffs stockpiling...); and non-structural solutions in order improve the performance of the sector (trade, drought management, insurance...).

References

Abid Karray J., Lhomme J. P., Masmoudi M.M. and Ben Mechlia N. (2008) Water balance of the olive tree–annual crop association: A modeling approach, agricultural water management 95 pp 575-586

Aldaya M.M., Carrido A., Llamas M. R., Valera-Ortega C., Novo P. and Casado R. R. (2010) Footprint and virtual water trade in Spain, Water policy in Spain, editors Alberto Carrido, M. Ramon Llamas, CRC Press,

Besbes, M., Chahed, J., Hamdane, A. and De Marsily, G. (2010) Changing Water Resources and Food Supply in Arid Zones: Tunisia. In: G. Schneider-Madanes & M.F Courel (eds.), Water and Sustainability in Arid Regions. Springer.

Boubaker T. and Mahfoudhi L. (1995) Secteur oléicole en Tunisie : situation actuelle et éléments de stratégie, Options Méditerranéennes, Sér. B / n°14, 1995 – pp 239-247

Chahed J., Hamdane, A. and Besbes, M. (2008) A comprehensive water balance of Tunisia: blue water, green water and virtual water. Water International, 33(4): 415–424.

FAOSTAT (2010) http://faostat.fao.org/site/569/default.aspx#ancor

Frigui, H.L. (2005) Rapport National sur la mise en valeur des ressources en eau en Tunisie. Nations Unies, Commission Economique pour l'Afrique ; CEA-AN/PUB/EAU/TN/7.

Galán C., García-Mozo H., Vázquez L., Ruiz L., Díaz de la Guardia D. and Domínguez-Vilches E. (2008) Modeling Olive Crop Yield in Andalusia, Spain, Agronomy Journal, Volume 100, Issue 1

Gargouri K., Rhouma A., Sahnoun A., Ghribi M., Ben Taher H., Ben Rouina B. and Ghrab M. (2008) Assessment of the impact of climate change on olive growing in Tunisia using GIS tools, Options méditerranéennes, Series A N°80

Ghrab M., Gargouri K. and Ben Mimoun M., (2008) Long-term effect of dry conditions and drought on fruit trees yield in dryland areas of Tunisia, Options méditerranéennes, Series A N°80

Hamdane, A. (2007) Tunisia National report on monitoring progress and promotion of water demand management policies. Water demand management in the Mediterranean, progress and policies. Blue Plan, Zaragoza, Spain.

Hoekstra, A.Y. and Chapagain, A.K. (2007) Water footprints of nations: water use by people as a function of their consumption pattern, Water Resources Management 21(1): 35-48

MARH (1998-2007). Annuaires des statistiques agricoles. Ministère de l'Agriculture et des Ressources Hydrauliques, Tunisie.

Rezgui, M, Ben Mechlia N, Bizid E, Kalboussi R. and Hayouni R. (2005) Étude de la stabilité du rendement de blé dur dans différentes regions de la Tunisie. In : L'amélioration du blé dur dans la région méditerranéenne : nouveaux défis. Options méditerranéennes, Sér A : Séminaires Méditerranéennes 2000 ; (40) : 167-72.

Thabet B. and Laajimi A. (2006) L'huile d'olive : un produit méditerranéen à valoriser davantage, les notes d'alerte du CIHEAM, N°14.

7. Water and the WTO: Don't kill the messenger

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Introduction

There are many similarities between the trade and water nexus and the trade and climate nexus. This is because the trade, water and climate communities face the common problem of free riding associated to a "public good". Free riding is well recognised in the case of water (and climate) even if water should not be treated as a pure public good (defined by non-rivalry and non-exclusion) but only as a local and common pool resource (Perry et al., 1997). Water resources become rivalrous only once the level of water exhaustion is reached (then their consumption by one individual reduces their availability for consumption by others). And, they are often non-excludable because of the failure to implement efficient property rights, such as those illustrated by the centuries-old system of "bisses" in Valais (a Swiss region). That said, today water production and consumption are subject to free-riding largely because domestic water policies are non-existing or embryonic: pricing mechanisms are not developed, externalities (water over-use, excessive use of pesticides and fertilisers, etc.) are not taken into account, etc.

In sharp contrast, the fact that freer trade is also largely subject to free-riding is often ignored today. However, the free-riding instinct re-emerges each time when, despite robust economic analysis and history, countries believe that they would be better off if they impose tariffs on their imports while getting free access to the markets of the rest of the world. If few today realise that freer trade is a public good, it is because the existing world trade regime has been very successful in inducing countries to limit their strong free-riding instincts in trade matters. Benefits from freer trade are bigger and faster to emerge because many countries move together within a well-designed world trade regime based on GATT/WTO principles and rules (in this paper, "rules" are meant subordinate to principles).

There is another deep connection between trade, water and climate. It is widely recognised that forecasting future climate shocks at a regional level—which regions will be flooded, which ones will be under water stress on a year by year basis—is largely out of reach. In such circumstances, trade gets back a role that has faded away during the last sixty years of relatively stable climatic, economic and political conditions. It is to be the ultimate insurer. Regions under sudden water stress will need to import food products in exceptional quantities, and trade happens to be a cheap (efficient) insurance scheme to face a sudden instability in water resources in some parts of the world.

There are thus good reasons to look at whether the world trade regime could provide a strong and sound framework to the international water regime. Not many papers have looked at this issue (Yang and Zehnder, 2007; Hoekstra, 2010). They generally see the WTO as a source of problems rather than of solutions. Hence, they argue for specific international agreements on water. But, the climate community experience of the COP15 (the 2009 Copenhagen Summit on Climate Change) is a strong warning signal showing how difficult it is to build a “specific” international regime.

In contrast, this paper argues that the basic principles on which the world trade regime is built would be equally useful for the international water regime, and that the WTO rules are flexible enough to address the specific problems raised by water management in an international context. It also argues that, if current international trade mirrors domestic distortions, limiting such trade will cost a lot in terms of water use. Killing the messenger (trade) does not solve the problems (domestic markets).

The paper is organised as follows. The second section provides a broad insight on how trade analysis shows the beneficial aspect of a more integrated international trade in water and how trade and water issues can be mutually supportive. The third section raises two questions. Do we need a specific international agreement for “trading water” (the various forms of such a trade are explained in this section)? Do we need specific international agreements for producing water in sustainable quantity and quality? The paper argues that the answer to the first question is no. The World Trade Organization (WTO) rules are both sound and flexible enough to address the key issues raised by water trade. The second question has a more complex answer. The paper suggests that some WTO rules may need to be revisited, but that such revisions are unlikely to create serious problems if they are carefully handled from a water and trade perspective.

Water and trade economics

Before looking at water economics in an international trade setting, two crucial remarks should be made. First, trade is the mere difference between domestic consumption and production. Import is the excess of domestic consumption over domestic production, export the converse. If domestic production and/or consumption are distorted, trade is distorted. For instance, if producers in the exporting and importing countries do not take into account negative externalities (pollution), the exporting country could export too much water-intensive goods and the importing country could import not enough such goods.

The fact that trade is a mere difference has a key corollary. It is that taking measures for restricting or increasing water trade is not the adequate solution to address production and consumption externalities since it does not address the initial problems raised by imperfect domestic water markets (production and/or consumption). These problems could be satisfactorily solved only by measures targeting domestic markets—better pricing mechanisms, more appropriate subsidies and/or taxes favouring investment and delivering productivity gains.

That said, if acting on international trade is not the solution, the rules of the world trade regime, if well interpreted, have the capacity to be conducive of improved domestic market disciplines, as underscored in the next section. This has already happened. The last sixty years have witnessed increased market access (trade liberalisation) in industrial products as a force pushing for reducing distortions in domestic markets in order to reap all the benefits from trade opening.

The second crucial preliminary remark is that, contrary to the politicians' and people's views, economists underscore the fact that imports capture the gains from trade, whereas exports mirror the costs of trade. Countries export only because they have to pay for imports. Exporting too much is as bad as importing too little. This is particularly obvious in the water sector where trade does not only generate movements of goods, but also entails exchanges of the quantity of water "embedded" in commodities—hence the concept of "virtual" water (the amount of water required to produce a good is "virtually" exchanged among countries through trade flows). In short, a country saves its scarce water resources by relying on imports, while it increases its water use by exporting water-intensive goods.

Comparative advantages

Middle East's virtual water imports in the form of grains are equivalent to the flow of the river Nile in a year (Allan, 2003). Explaining such trade flows requires nothing more than a direct application of comparative advantages theories (Wichelns, 2010). The virtual water notion is thus a relatively new concept based on well-established ideas in international economics.

The theory of comparative advantages splits into two main tenants: the Ricardian theory and the Heckscher-Ohlin theory (hereafter HO). Both analyses show that by specializing in productions for which they enjoy a relative advantage, countries opening to trade breed a process that drives to a globally and economically more efficient use of resources than in autarky. These theories of comparative advantages tell us that all countries have an interest to trade, even if they have only a relative advantage in the production of some goods. That a country may produce all the goods more costly than its trading partner does not prevent it to have a relative (comparative) advantage in the goods it produces in a relatively less costly way than its trading partner.

The Ricardian approach perceives comparative advantages as arising from technology-driven differences in factor productivities among countries. Indeed, Ricardo used "climate differences" to express the relative productivities of two trading partners to engage into trade. The opportunity cost of using water as an input (compared across countries) is what drives Ricardian comparative advantages (for more, see below Table 7.1).

By contrast, the HO approach perceives countries' comparative advantage as determined by the relative abundance in production factors (capital, labour and natural resources, such as water) among countries. Shifting to HO offers an interesting perspective. International trade in goods is rooted in exchanges of factor services through which a country can "enlarge" its scarce and relatively unavailable resources. In this sense, the concept illustrates how trade in goods can be a substitute to factors' (such as water) immobility among distant countries and that trade is mutually beneficial. So, trade may have an alleviating impact on water stress nationally, regionally, and globally if a trade policy allows for the full beneficial effect of these forces. In this context, trade can entail positive externalities by contributing to favour efficient water uses globally.

Table 7.1 illustrates the two approaches. It displays labour force (active population), land and water endowments as well as factor intensities for 2000 in ten countries. Compared to the situation in France, China benefits from large endowments in labour, water and land (columns 1, 2 and 3). Yet, in terms of water endowments, China is relatively more abundant in labour and less abundant in land than France (column 4 and 5). In Column (6), relative water requirements of countries are reported with respect to France. This means that a country with a ratio above unity is less efficient in producing wheat than France. For instance Canada with a high water endowment and being more water intensive than France (Canada's amount of water per worker is higher) has nonetheless lower water productivity in wheat than France. The sample used here is too narrow to draw general conclusions. It however conveys the idea that a country may well be Heckscher-Ohlinian with one country and Ricardian with another. This pledges for considering both sources of comparative advantages. It is crucial to see also that both types of comparative advantage need to be implemented if one wants to correctly capture the virtual water issue.

Table 7.1. Water, land and labour endowments and factors intensities (2000).

				Heckscher-Ohlin approach		Ricardian approach
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	Renewable water [a]	Uncategorised labour [b]	Arable land [b]	Water per workers	Water per Ha of arable land	Wheat productivity relative to France [c]
Brazil	8,233	77	58	106	142	1.8
Canada	2,902	16	46	183	63	1.7
China	2,830	737	133	3.8	21	0.7
Egypt	87	19	3	5	29	2
France	204	26	18	8	11	1
India	1,908	402	163	5	12	1.9
Israel	2	2	0.3	1	7	3.7
Japan	430	68	4	6	108	0.8
Mexico	457	34	25	13	18	1.2
United States	2,071	141	175	15	12	0.9

Notes: [a] International Labor Organization of the United Nations. [b] Food and Agriculture organization of the United Nations. [c] Ratio of each country water requirement for wheat production to the one of France. If the ratio is above one then the country has a lower productivity than France (and vice versa).

From trade theories to water realities

Literature has provided evidence that virtual water flows of a country is not necessarily related to the abundance and/or scarcity of renewable freshwater (Yang and Zehnder, 2007). Yet, one must distinguish between the water content of trade e.g. (virtual water) and trade itself. This distinction means that even if virtual water is not related to abundance in water, water availability may still play a role in shaping trade flows. And, the HO model refers to predictions concerning trade in goods and not to implicit trade in the factor services embodied in those goods (e.g. virtual water). It is thus incorrect to mobilise the HO theorem and to conclude on its poor performance when one investigates the relationship between virtual water flows and water endowments (Kumar and Singh, 2005; Verma et al., 2007). In this theoretical context we need to look at trade flows only.

Does the HO model perform well in this context? An extensive test of the HO model provides evidence that international trade is well explained by the relative uneven distribution of production factors including water resources (Le Vernoy, 2011). In other words, trade in agricultural products is effectively shaped by the relative abundance and/or scarcity of water. And, this is sufficient to conclude that the virtual water concept is a useful tool to connect the trade and water nexus.

That said, there are very good reasons to look at the HO model as an imperfect model to capture perfectly the water situation. These imperfections are examined by increasing order of importance.

First, while water is still largely immobile among distant countries the question of contiguous nations sharing common resources should be integrated. Further research could relax the assumption of perfect immobility by acknowledging the strategic importance of the existence of upstream/downstream relationship between any two trading partners (Ambec and Ehlers, 2007). Second, other determinants may be at work, such as geographical and institutional characteristics of each trading partners and distortive trade policies. Geography and climate play a major role (the issue of distortive trade policy instruments is discussed in the next section). Last but not least, the pricing mechanism in the water sector is highly distorted. Many countries do not charge a price for water, especially for by far the largest water users—farmers. Water is not priced at all in some countries, pushing the water sector into a "tragedy of the commons". Failures to ensure accurate property rights of the resource should be managed through adequate price mechanisms and regulations. An even more widespread reason is the question of subsidies. Many countries subsidised water provision to a point that the signal of scarcity is totally distorted (Boulanger, 2007).

Are WTO disciplines appropriate to water trade?

At the onset of this section, it is important to ask the following question. What would be the cost of rejecting the WTO-based approach that today rules virtual water? Such a refusal would open the possibility of banning imports and/or exports any time. Estimates suggest that current virtual water trade allows saving, on average, 22 per cent of the world water (Chapagain et al., 2006). This figure represents a rough estimate of the minimal opportunity cost of rejecting a WTO-based approach. And this is despite the fact that the current trade regime is not fully developed in order to address water issues and that it operates under very distortive domestic water policies (no pricing mechanism and recognition of externalities).

In this context, examining the use of the WTO disciplines in the water sector raises three questions. Is water a tradable good? Are the two key WTO principles (national treatment and most-favoured nation) appropriate pillars for a water trade regime? Do the other WTO rules accompanying the WTO principles (again, in the paper context, "rules" are subordinate to principles) offer the flexibility that may be needed by the specifics of water trade?

Is water a tradable good?

This question has received a positive answer from an economic perspective in the introductory section. What follows deals with the international law-related aspects of the issue. In other words, can water be seen as a tradable good in the WTO legal context? A first answer can be found in the tariff classification (the so-called "Harmonised System", or HS) which describes the whole universe of products and is used by every Customs in the world. In this context, it is useful to make a basic distinction between freshwater and waters having a saleable form (for instance, bottled waters). This latter form is clearly within the WTO scope since there are tariff lines for saleable waters (see Table 7.3 under the HS 2201-10 code).

Table 7.2. Implicit tariff rates on virtual water, 2007.

	Applied tariffs (%)			Bound tariffs (%)		
	Developed countries	Developing countries and LDCs	All countries	Developed countries	Developing countries and LDCs	All countries
Fishery	2.2	15.1	14.2	2.5	34.2	31.4
Forestry	0.6	6.5	6.1	1.2	28.9	26.5
Fuels	0.5	6.2	5.8	1.5	27.5	25.3
Mining	0.8	6	5.7	1.6	30.9	28.6
All merchandise imports	5.4	10.7	10.3	[c]	[c]	[c]
Virtual water: animal [a]	2.8	10.5	6.7	22.3	58.1	40.2
water requirements [b]	6726	10066	8396	6726	10066	8396
Virtual water: crops [a]	5.6	13.8	9.7	28.6	58.9	43.8
water requirements [b]	3319	5753	4536	3319	5753	4536

Source, WTO Report 2010, pp. 114-115, WITS. [a] Virtual water associated to animals and crops. [b] Average water requirements (cubic meter per ton). [c] non available in the WTO Table 8, p.115.

Table 7.3. Water in the Harmonised System of classification of goods.

Headings/Subheading	Article Description
22	Beverages, spirits and vinegar
2201	Unsweetened beverage waters, ice and snow
2201-10	Mineral and aerated waters not sweetened or flavoured
2201-90	Ice, snow and potable water not sweetened or flavoured

Source: UN Comtrade commodities list description. http://comtrade.un.org. Note: Chapter 22 does not cover: (i) products of this chapter (other than those of heading 2209) prepared for culinary purposes and thereby rendered unsuitable for consumption as beverages (generally heading 2103); (ii) sea water (heading 2501); (iii) distilled or conductivity water or water of similar purity (heading 2853).

More challenging—but much more crucial from an environmental and efficient perspective if only because of its sheer size—is the freshwater case. Freshwater could be divided into two components: bulk water traded via pipeline or ships, and "virtual" water traded as input of other products, mostly farm products.

To our knowledge, there is no exhaustive review of how bulk water is treated. There are cases of export bans (Canadian water in the NAFTA context). But, there are also cases of trade in bulk water (intra-EU trade cases or projects) and it would be interesting to know how EC Customs have treated such bulk water. However, trade in bulk water is costly with the current technologies so that it will represent only a small problem for a long time to come. Finally, the treaties on water sharing among countries having access to a large common river (Danube, Nile, etc.) amount mostly to quota systems designed in terms of production ("water use") not of trade stricto sensu (less than a third of international water treaties deal with financial or economic payments among countries (Dinar, 2008)).

The core of the water trade problem is thus the treatment of "virtual" water trade. For some commentators (WTO 2010), such a trade is still potentially covered by WTO principles and rules since the HS 2201-90 code includes ice and snow, two forms of freshwater that human beings do not drink except in extreme cases (see Table 7.2). For other commentators, the general heading under which waters are included (the HS 22 code) is beverages, meaning that waters under the WTO disciplines should be limited to the forms of water fit for consumption. This argument is not fully convincing because it relies on consumption defined as household consumption. But, today international trade flows are dominated by trade in intermediate goods, that is, goods "consumed" by firms for producing other goods. Virtual water fits perfectly this dimension.

Building a framework for the world water regime

Such a context raises two questions. Which would be the principles and rules of the world trade regime that the world water regime should borrow because it will benefit from them? Which are the specific rules that the world water regime should establish? These questions suggest that the world water regime could rely on three main pillars illustrated in Figure 7.1:

- the WTO principles of non-discrimination (national treatment and most-favoured nation (MFN) which do not need to be adjusted in order to fit the needs of the world water regime;
- a series of WTO rules which should be adjusted in order to fit the needs of the world water management;
- and a specific water agreement which would answer questions specific to the water issue with no real equivalent in the trade regime.

The following sections examine in more detail these three pillars.

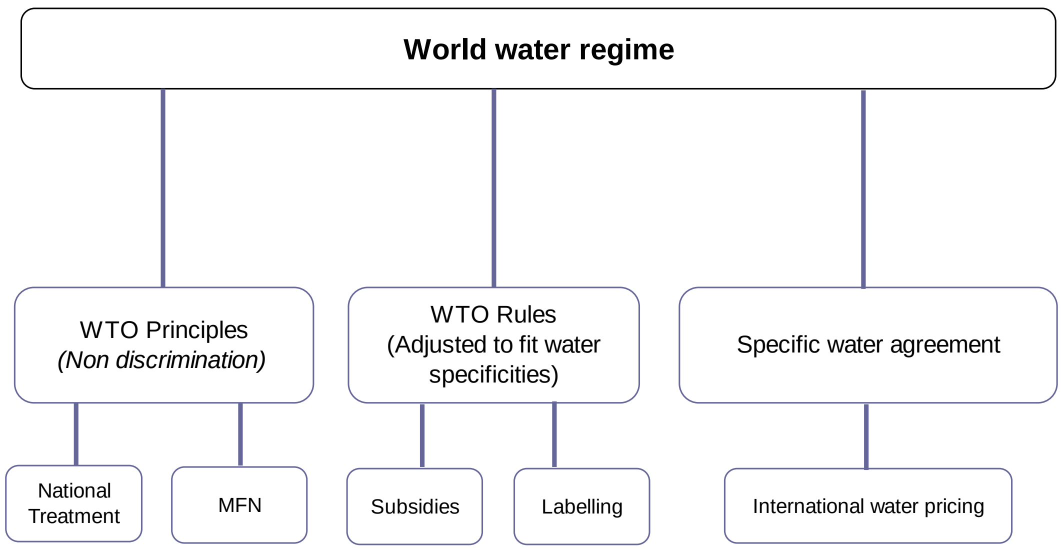

Figure 7.1. Organizing the world water regime.

The two fundamental WTO principles

There are two fundamental WTO principles—"national treatment" (NT) and "most-favoured nation" (MFN)—which, combined, define the "non-discriminatory" approach which is the basis of the modern world trade regime run under the GATT/WTO aegis.

The MFN principle (GA Article I) requires that a country imposes the same tariff on the imports of a given good independently from the country of origin. The General Agreement on Trade and Tariffs is both a text (hereafter GA) and an institution (the GATT Secretariat, hereafter the GATT). The WTO is the heir of both the GA and the GATT. This principle is already de facto applied on virtual water since most tariffs imposed on farm products are MFN. There is an exception to the MFN principle, namely the possibility to conclude "free trade agreements" of various kinds under GA Article XXIV. Water trade benefits such preferential duties (often zero) to the extent that FTAs cover farm trade—but most FTAs do not cover farm trade. As MFN virtual water tariffs tend to be high (see Table 7.2), the zero-tariff FTAs are likely to generate large distortions in the virtual water trade flows—reducing the trade flows from countries outside the FTAs (for instance, non-EC countries) and increasing the trade flows from inside the FTAs (for instance, among EC Member States) independently from the water resources available inside and outside the FTA under scrutiny. This feature illustrates the importance of the benefits from the MFN principle in the water case.

The NT principle (GA Article III) requires that a country should impose the same domestic tax(es) on the goods imported and on the "like-products" produced domestically. In other words, NT intends to create a level playing field between foreign and domestic products in domestic tax matters. It is necessary to avoid that a progressive liberalisation via tariff cuts would be eroded by increases of domestic taxes on foreign products alone. In the current trade regime, virtual water is covered by NT since the products in which water is included are covered.

These two non-discrimination principles often generate negative reactions because they seem to limit considerably the sovereignty of a country. This is particularly the case when precious natural resources, like water, are at stake. This impression flows from two totally different, but convergent, perspectives that are worth examining briefly.

First, the water community focuses on the (economically attractive) idea of a "world price" for water (as the climate community looks often to a world price for CO2). An unique world price of water would prevail when all the marginal costs of using water in the vast world would be equalised. Of course, this situation would probably never be reached for a couple of reasons. First is that water prices should reflect the different water qualities available in the world (as there are different quality-adjusted oil prices). Second, a unique quality-adjusted world price of water would require strict conditions to be met, such as instantaneous and perfect information on all the water markets in the world as well as instantaneous and perfect interconnections of all the water markets in the world. However, a "world price" for water is a concept useful to keep in mind in order to remember that the various world prices in the world will interact and, to some extent, may converge—in particular under the influence of trade in water. However, this purely economic approach relies on the political illusion (today) that the world is an unified entity. The COP15 has clearly revealed how much the real word is a multilateral forum where each country is unapologetic to defend its own interests at the expense of the other countries. This does not mean that, in a distant future, there will not be one world price for water. But, it will be the result of a long process of building interconnected markets. Indeed, there is a clear parallel between the long road ensuring a progressive convergence of domestic water prices to a world water (positive) price and the long road ensuring a progressive convergence of national tariff cuts to worldwide zero tariffs.

Since its origin, the WTO has evolved in a multilateral world, where the MFN/NT principles aim at helping all the countries to converge to the economically attractive one world (meaning no trade barriers at all in the very long run) while leaving some room for the countries' strongest interests via flexible rules (described briefly below).

Second, the GATT/WTO history conveys a very realistic view of the limits of the national governments. Trade policies are the endless tale of governments captured by vested domestic interests. They show the limits of the "internal" sovereignty of governments—their inability to balance the various domestic interests in a fair way and their propensity to favour the most aggressive (even if they are very small in numbers of people) lobbies. It happens that the water sector is at the crossroads of two extremely powerful lobbies—water firms and, above all, farmers. Import-competing farmers will try to reduce virtual trade below its optimal level (i.e., a level based on sound economic concerns) while exporting farmers will try to inflate virtual trade above its optimal level. The extent to which the MFN/NT principles are an obstacle to the risks of water policies being captured by domestic vested interests makes them crucial for the water community as well as for the trade community.

Flexibility of the WTO rules

That the WTO principles offer a robust framework for an international water regime does not mean that the current WTO rules (i.e., disciplines subordinate to the non-discrimination principles) are flexible and sufficient enough to address all the specific issues raised by the water sector. Three main issues deserve attention.

Non-discrimination, "like" product and water labelling

The first question is about water "quality". Not depleting the current stock of water does not necessarily mean that water quality is kept intact or improved. It is well known that, if the agricultural policies of the rich countries have not—so far—seriously reduced global water availability, they have often been dramatically detrimental to water quality due to excessive use of fertilisers, negative externalities caused by "industrial" cowsheds or pigsties, etc.

In the WTO usual approach, non-discrimination makes sense when applied to "like-products", with "likeness" being defined by the tariff line describing a product. In short, two products pertaining to the same tariff line are assumed similar.

This crude but pragmatic approach ignores the key question of the process and production methods (PPMs) that is crucial for the water community. Is a product having used clean water similar to a good having used polluted water? In more general terms, should not one pay attention to the "water footprint" of farm products? These questions are legitimate, especially when water use is reaching the sustainability threshold in many regions in the world. The debate in the water case has not exactly the same intensity than in the climate case. Winds make "clean" air easily a worldwide public good. As stressed in the introduction, clean water is a more local good—hence much more amenable to national appropriate measures.

Defining products as different if they have different water contents/qualities (because of different production processes) is a prospect that makes the trade community very nervous for the following, very basic, reason: the sheer complexity generated by adding the dimension of production processes. Today, there are roughly 10,000 different tariff lines defining "products" in a typical tariff schedule. Taking into account the various water production processes capable to obtain each of these products would require to define tariff lines in terms of "products times production processes". Such a challenge is not new in the world trade regime. "Rules of origin" which determine the country of origin of a product are creating a similar problem. But, precisely, the trade community is aware about the costs of such a complexity. For instance, the existing rules of origin in the NAFTA context are estimated to be equivalent to a price increase of 12 per cent (Cadot et al., 2005).

The water issue has the capacity to generate such problems to an extent unknown before. Pushed to its extreme, it could easily negate the notion of similar products that is so essential in a world economy witnessing an endless expansion of varieties of products in order to better satisfy consumers. The climate literature revealing the full extent of the problems of implementing climate change policies in an international context is relatively recent (Brenton et al., 2009; Jensen, 2010; Moore, 2010). It shows that an unrestrained PPM logic would require a gigantic database generating astronomical transaction costs (assuming that the needed data would exist). Such costs would be compounded by the huge risks of corruption that are inevitably associated to complexity in an international context. They would also divert attention from the main sources for saving water—appropriate production and consumption habits. Finally, such risks and costs would be (much) higher for the emerging and developing countries, whereas those countries should be induced—not inhibited—to participate to a world water regime.

As in the climate case, there is thus a strong need to strike a delicate balance between exhaustiveness and similarity (Messerlin, 2010) if one does not want to loose the savings (gains) brought by international trade of virtual water. This balance is a question largely in the hands of the water community. It is in the interest of the water community both to ensure water quality and to favour the best use of the existing water resources by allowing freer trade among undistorted domestic water markets.

A water label has been proposed for handling this issue. Such a solution would respect the balance between exhaustiveness and similarity if it is limited to the few highly water-intensive commodities, such as rice, cotton, paper or cane sugar, as already suggested (Hoekstra, 2010). A water label is compatible with the WTO principles of non-discrimination as long as it is defined on a scientific basis, a condition likely to be met if the label is defined by an international agreement on water-labelling—the equivalent of the Codex Alimentarius for food products. Of course, WTO-compatibility does not mean that water labelling would be easy to do, hence would be desirable (Hoff et al., 2010). It simply states that such a road, if found desirable, is possible within WTO-compatible rules.

As it is allowed by the WTO Agreement on Sanitary and Phytosanitary Measures, a country could adopt a stricter definition of water quality as long as such a definition would be based on clear scientific justifications—a condition the main goal of which is to ensure that the country avoids to create "unnecessary" obstacles to water trade.

Water footprint and international water pricing control

It is argued that the limited availability of freshwater in the world implies a ceiling for human kind's water footprint. This situation has been understood as requiring that the global water stock should be "fairly" shared among countries by creating an international water-footprint permit system (that is, by issuing permits per country) (Hoekstra, 2010).

The WTO legal framework per se has little to say on such a scheme. But, the experience of the trade community suggests that such a proposal faces two problems. First is political. It is hard to imagine that water-rich countries would surrender their sovereignty on their existing domestic stocks of water. As underscored above, such a proposal relies on the view that we live in an unified world—not in a multilateral one. The second problem is the allocation process of water permits. The half century-long experience of the trade community is that quotas (permits) are the most difficult instrument to handle for allocating scarcity in an international environment, and that, as a result, they often end up as a unfair and perverse tool. Unfair because they tend to favour the most powerful countries at the time of their creation. Perverse because they create rents that give to their initial beneficiaries a massive leverage (power and money) for keeping unchanged the initial scheme while the world is changing.

Much more attractive would be efficient systems of water-pricing at the local and national level, converging progressively to a world price of water (adjusted for water quality as said above). The water community underscores that there is a huge opposition to "pay for water" (Catley-Carlson, 2010). However, this opposition at large seems declining in developed countries, and focusing on the question of whether the existing pricing system is well conceived and/or implemented (rather than on the principle to pay). However, unsurprisingly, there is one strong core exception to this evolution: the farmers who are the main users of water.

An international water pricing agreement would not be inconsistent with the WTO if it does not create discrimination among countries—and there is no reason that it does want to do so. Such an agreement may be hard to negotiate when many countries have no domestic pricing mechanism and when there is a strong opposition by farmers. One way to accelerate the creation of domestic pricing schemes would be to rely on international institutions that will be increasingly involved in the water issue. The World Bank and key regional banks (African Development Bank, Asian Development Bank, etc.) could lay down more systematically the basic components or guidelines for creating and managing domestic markets in water. Such a non-governmental initiative could then serve as a basis for an international pricing agreement that countries would join when they start to run their water markets in an efficient way.

Subsidies, taxes and domestic regulations

Water is a too multi-faceted product to believe that the introduction of pricing and markets would address all these facets. Subsidies, taxes and domestic regulations are likely to be part of a satisfactory solution to domestic efficient water regimes.

There are "bad" and "good" subsidies. Today, bad subsidies may prevail in the water sector. Too often, farmers benefit from subsidies inducing them to over-use water, to create subsidy-based droughts or water-stress, and to destroy alternative activities (for instance, water subsidies in the French region of Poitou-Charente have hardly hit oyster-producing and fishing activities associated to local rivers) (Boulanger, 2007).

The WTO strict disciplines on subsidies having an impact on trade are thus useful in the sense that they constitute an obstacle to such bad subsidies. That said, such disciplines are far to be perfect. First, they do not cover subsidies wasting water, but having no impact on trade flows. Secondly, requirements for the subsidizing country to eliminate its subsidies are missing. Rather, they open the possibility for importing countries to impose "anti-subsidy" tariffs on the subsidised products from trading partners. Such measures tend to be imposed mostly by countries having import-competing activities (for instance, in farm products) with two negative consequences: such measures are imposed because the import-competing farmers are not efficient (with respect to saving water), and they leave a lot of export markets to the products using subsidised water. A parallel could be made between freshwater and pre-harvested trees. Both are potential inputs to farm goods (water) and wood products (trees). There is an ongoing saga of trade conflicts about trees between the US and Canada, with the US imposing anti-subsidy measures on Canadian lumber on the basis that Canadian laws on forests grant implicit subsidies to Canadian producers of softwood products. In the first case, trade and water use are both hurt—hence the trade and water communities have common interests to improve the disciplines. In the second case, trade is not hurt, but the water community has clear interests in improving the rules (and the trade community has nothing to object).

"Good" subsidies in water may be crucial in the coming years to the extent that the sustainability threshold in water use is close to be reached in many places. Such a situation is likely to require public investments and regulations inducing public institutions and private firms to invest enough in water "production" and conservation. In other words, there is a need to make sure that such subsidies and regulations would be immune to the current WTO rules ("non-actionable" in the WTO legal jargon). Such exceptions existed (for instance, in the case of research and development) or are still existing (in the agricultural sector for developing countries). But, there is a need to review carefully all these exceptions and to craft the new rules in the best interest of worldwide water management.

A last instrument deserves a quick comment. The WTO rules ban export quantitative restrictions, but allow generally export taxes (an awkward situation). The ban of export quotas makes sense from a water perspective to the extent that such quotas are implicit subsidies to the domestic consumers of water—hence running the risks of wasting water (a departure from the world water price). Allowing export taxes introduces distortions in the world economy which were very visible during the 2007-2008 food crises, caused in part by some exporting countries' ban of exports (Argentina, Vietnam, among others). Exporting countries of farm products were using export taxes to raise the world farm and food prices with adverse effects on the importing countries, but also ultimately on their exporters. Here again, better WTO rules are needed.

Concluding remarks

The paper argues that the two WTO principles of "non-discrimination" are necessary for an economically sound water trade. But they are not sufficient. Other international disciplines will be needed—on labelling, subsidies, taxes and regulations. In this respect, the existing WTO rules are roughly what is needed. But they require to be improved in order to better contribute to a more efficient water management from the world point of view. Improving these WTO rules would allow more open virtual water markets, and increase the pressures for improving the functioning of domestic markets, too much distorted today by the absence of domestic pricing mechanisms or by unsound economic policies.

The flexibility of the WTO rules seems wide enough not to bother too much with the GA Article XX on "General Exceptions". Some of these GA Article XX exceptions could easily fit water issues: for instance, paragraph (g) on conservation of exhaustible resources or paragraph (b) for protecting health. The key conditions for using GA Article XX (not constituting an arbitrary or unjustifiable discrimination between countries and a disguised restriction on international trade) are consistent with the desire to create progressively a worldwide water pricing regime. But the GA Article XX stops short of suggesting adequate measures for really solving the problems. For instance, the true way to conserve exhaustible resources is to make adequate investments, hence the need of appropriate rules on subsidies and domestic regulations. The better these rules will be, the lower the need for using the GA Article XX will be.

References

Allan, J. (1997) Virtual water: a long term solution for water short middle eastern economies? In: Paper presented at the 1997 British Association Festival of Science, Roger Stevens Lecture Theatre, University of Leeds,Water and Development Session.

Ambec, S. and Ehlers, L. (2007) Cooperation and equity in the river sharing problem. Working Papers 200705, Grenoble Applied Economics Laboratory (GAEL).

Ansink, E. (2010) Refuting two claims about virtual water trade. Ecological Economics, 69 (10), 2027-2032.

Boulanger, P. (2007) A flood of euros for irrigated fields. Policy Brief. Groupe d'Economie Mondiale. Sciences Po. http://gem.sciences-po.fr/

Bowen, H. (August 1983) Changes in the international distribution of resources and their impact on US comparative advantage. The Review of Economics and Statistics 65 (3), 402-14.

Cadot, O., Carrère, C., Melo, J. de and Portugal-Pérez, A. (2005) Market access and welfare under free trade agreements textiles under NAFTA, World Bank Economic Review. Vol.19, #3, pp. 379-405.

Catley-Carlson, M. (2010) Ten random thoughts: Might the world be able to find ways to talk about water and trade? Paper prepared for the workshop on “Accounting for water scarcity and pollution in the rules of international trade”, Amsterdam 25-26 November 2010.

Chapagain, A.K. and Hoekstra, A.Y. (2008) The global component of freshwater demand and supply: An assessment of virtual water flows between nations as a result of trade in agricultural and industrial products. Water International 33(1): 59-110.

De Fraiture, C., Cai, X., Amarasinghe, U., Rosegrant, M. and Molden, D. (2004) Does international cereal trade save water? The impact of virtual water trade on global water use, Comprehensive Assessment Research Report 4, IWMI, Colombo, Sri Lanka.

Dinar, S. (2008) International Water Treaties. Negotiation and cooperation along transboundary rivers. Oxon: Routledge, 2008.

Hoekstra, A.Y. (2010) The relations between international trade and freshwater scarcity. WTO Staff Working Paper ERSD-2010-05. January 2010.

Hoff, H., M. Falkenmark, D. Gerten, L. Gordon, L. Karlberg, and J. Rockström (2010) Greening the global water system. Journal of Hydrology 384(3-4): 177-186.

Lamy, P. (2007) “Friend, not foe”. In “Connected dreams, globalization and the environment”. Our Planet Magazine. UNEP.

Le Vernoy, A. (2011) The nuts and bolt of trade in virtual water, GEM Working Paper, Groupe d’Economie Mondiale, Sciences Po-Paris.

Messerlin, P. (2010) Climate change and trade policy From mutual destruction to mutual support. a contribution to the DFID-World Bank Global Trade and Finance Architecture project, Working Paper. Groupe d’Economie Mondiale at Sciences Po. http://gem.sciences-po.fr/.

Mussa, M., (November 1979) The two-sector model in terms of its dual: A geometric exposition, Journal of International Economics 9 (4), 513-526.

Perry, C. J., Rock, M. and Seckler, D. (1997) Water as an economic good: A solution, or a problem? Research Report 14. Colombo, Sri Lanka: International Irrigation Management Institute.

Verma, S., Kampman, D. A., van der, P. Z. and Hoekstra, A. Y., (2007) Going against the flow: A critical analysis of virtual water trade in the context of India’s national river linking programme.

World Trade Organization (2010) World Trade Report: Trade in natural resources. WTO. Geneva.

Wood, A. (1994) Give Heckscher and Ohlin a chance! Review of World Economics (Weltwirtschaftliches Archiv), 130 (1), 20-49.

Yang, H., and Zehnder, A. (2007) “Virtual water”: An unfolding concept in integrated water resources management, Water Resour. Res., 43, W12301.

Programme of the Workshop

Thursday 25 November 2010	
08.30	Registration and welcome
09.00 – 09.10	Introduction by **Arjen Hoekstra**, Professor, University of Twente
09.10 – 10.30	How to incorporate a wise and fair virtual water trade into international trade rules Chair: **Patrick Messerlin**, Professor, Sciences Po. • **Tony Allan**, SOAS and King's College London • **Peter Rogers**, Harvard University - *Failure of the Virtual Water Argument* • **Alberto Garrido**, Technical University of Madrid - *International Farm Trade: Does it Favour Sustainable Water Use Globally?* • **Holger Hoff**, Potsdam Institute for Climate Impact Research - *Real water-virtual water interactions: A model based analysis of green and blue water productivity, scarcity, and trade*
10.30 – 11.00	Coffee break
	• **Taikan Oki**, University of Tokyo - *How virtual water trade and water footprint can be beneficial, practical, and useful?* • **Jacob Granit**, Stockholm International Water Institute • **Junguo Liu**, Beijing Forestry University • **Jamel Chahed**, National Engineering School of Tunis - *Controlling water scarcity by optimizing blue and green virtual water fluxes: the case of Tunisia*
12.20 – 13.20	Lunch
13.20 – 14.20	How to incorporate a wise and fair virtual water trade into international trade rules Chair: **Margaret Catley-Carlson**, WEF Global Agenda Council on Water • **Daniel Zimmer**, World Water Council • **Caroline Sullivan**, Southern Cross University • **Hong Yang**, Swiss Federal Institute for Aquatic Science and Technology
14.20 – 14.50	Coffee break
14.50 – 16.10	• **Joppe Cramwinckel**, World Business Council for Sustainable Development • **Magdy Hefny**, Egyptian Ministry of water resources & irrigation • **Mohamed Ait Kadi**, Global Water Partnership - *The Water-Agriculture-International Trade Nexus: Morocco's case*
16.10 – 16.20	Introduction by **Bernard Avril**, European Science Foundation
16.20 – 17.30	Break into 2 working groups Objective: discuss the challenges and opportunities on incorporating virtual water trade into trade rules. Each group will discuss separately about the remaining scientific challenges and the related policy formulation and implementation. Chairs: **Aslihan Kerç**, ESF-LESC member & **Pieter Hooimeijer**, ESF-SCSS member Rapporteurs: **Ines Dombrowsky**, German Development Institute & (tbc)
17.30 – 18:00	Plenary session, with short debriefing from both working groups

Friday 26 November 2010	
09.00 – 09.10	Introduction by **Maite Aldaya**, University of Twente and UNEP
09.10 – 10.10	Elaboration of recommendations for research and guidelines for policy-makers on enhanced international virtual water trade – Global context Chair: **Caroline Sullivan**, Southern Cross University • **Margaret Catley-Carlson**, WEF Global Agenda Council on Water - *Might the World be able to find ways to talk about Water and Trade?* • **Vesile Kulacoglu**, WTO Trade and Environment Division • **Patrick Messerlin**, Sciences Po. Paris - *Water and the WTO*
10.10 – 10.40	Coffee break
10.40 – 12.30	• **Ricardo Melendez-Ortiz**, International Centre for Trade and Sustainable Development • **Tim Swanson**, Centre for International Environmental Studies, The Graduate Institute, Geneva • **Gerard Payen**, International Federation of Private Water Operators (AquaFed)
12.30 – 13.30	Lunch
13.30 – 15.30	Elaboration of recommendations for research and guidelines for policy-makers on enhanced international virtual water trade – European context Chair: **Ricardo Meléndez-Ortiz**, International Centre for Trade and Sustainable Development • **Peter Gammeltolft**, Protection of Water and Marine Environment Unit, EC Directorate General for the Environment • **Beate Werner**, Water Group, European Environmental Agency • **Andrea Tilche**, Unit Environmental Technologies and Pollution Prevention, EC Directorate General for Research • **Sergey Moroz**, WWF European Policy Office
15.30 – 16.00	Coffee break
16.00 – 18.00	Plenary session: Synthesis and Future Plans Chair: **Arjen Hoekstra**, University of Twente Rapporteur: **Bernard Avril**, European Science Foundation Presentation of the draft conclusions Discussion and agreement on the main strategic conclusions Next steps, list of actions

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