Ecological Economics 101 (2014) 43–53

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Valuing the impact of trade on local blue water

Anne Biewald [a,*], Susanne Rolinski [a], Hermann Lotze-Campen [a,b], Christoph Schmitz [a], Jan Philipp Dietrich [a]

[a] Potsdam Institute for Climate Impact Research, Telegraphenberg A 31, 14473 Potsdam, Germany
[b] Humboldt University of Berlin, Unter den Linden 6, 10099 Berlin, Germany

ARTICLE INFO

Article history:
Received 7 August 2012
Received in revised form 6 January 2014
Accepted 6 February 2014
Available online 14 March 2014

Keywords:
Virtual water
Blue and green water
Water scarcity
Agricultural trade

ABSTRACT

International trade of agricultural goods impacts local water scarcity. By quantifying the effect of trade on crop production on grid-cell level and combining it with cell- and crop-specific virtual water contents, we are able to determine green and blue water consumption and savings. Connecting the information on trade-related blue water usage to water shadow prices gives us the possibility to value the impact of international food crop trade on local blue water resources. To determine the trade-related value of the blue water usage, we employ two models: first, an economic land- and water-use model, simulating agricultural trade, production and water-shadow prices and second, a global vegetation and agricultural model, modeling the blue and green virtual water content of the traded crops. Our study found that globally, the international trade of food crops saves blue water worth 2.4 billion US$. This net saving occurs despite the fact that Europe exports virtual blue water in food crops worth 3.1 billion US$. Countries in the Middle East and South Asia profit from trade by importing water intensive crops, countries in Southern Europe on the other hand export water intensive agricultural goods from water scarce sites, deteriorating local water scarcity.

1. Introduction

Water scarcity is a local phenomenon susceptible to global food production and its changes, since agriculture has the largest share in the consumption of global freshwater resources (Molden, 2007). With a growing world population and changes in dietary habits (Pingali, 2007), the demand for agricultural production and thus the demand for fresh water will increase in the future (Rosegrant and Sombilla, 1997; Vörösmarty et al., 2000). In this context international trade of virtual water, i.e. water embedded in agricultural goods, as defined by Allan (1996), plays an important role for local water availability now and in the coming decades. According to Hoekstra and Mekonnen (2012), roughly one quarter of the water used in global agricultural production can be assigned to virtual water exports.

Falkenmark and Lannerstad (2010) estimate that it will be necessary by 2050 to double the virtual water trade in order to compensate agricultural water deficits. In this sense the International Water Management Institute (IWMI) and the Government Office for Science (Government Office for Science, London, 2011; Molden, 2007) both state that an increase in global food trade and the consequent virtual water flows will offer the possibility of relieving water stress and a more efficient use of global water.

As several studies show, the main share of the virtual water in agricultural trade is green water (precipitation-derived soil water), while the share of blue water (runoff-derived liquid water resources)[1] is relatively small (Aldaya et al., 2010; Fader et al., 2011; Hanasaki et al., 2010; Hoekstra and Mekonnen, 2012; Yang et al., 2006). These results highlight the relevance of rainfed agriculture and, therefore, of land management in addition to blue water management.

Virtual water trade and the respective savings through trade of agricultural goods are quantified in a number of studies. Global estimates of virtual water flows related to crop trade were given e.g. by Hoekstra and Hung (2005), Yang et al. (2006), Aldaya et al. (2010), Fader et al. (2011) and Mekonnen and Hoekstra (2011). The respective savings related to different agricultural goods were determined by Oki and Kanae (2004), Chapagain and Hoekstra (2008), Hanasaki et al. (2010) as well as Hoekstra and Mekonnen (2012).

In recent years, the distinction between green and blue water was taken into consideration for calculating virtual water flows. Virtual blue and green water exports were estimated for all agricultural goods together (Hanasaki et al., 2010; Hoekstra and Mekonnen, 2012) as well as for different crop types (Fader et al., 2011; Mekonnen and Hoekstra, 2010, 2011).

The calculation of virtual water flows in the literature cited above is based on national trade statistics and average virtual water contents of the export countries. The respective savings are calculated as the difference of virtual water used in the exporting countries and the virtual

---

* Corresponding author.
E-mail addresses: Anne.Biewald@pik-potsdam.de (A. Biewald), Susanne.Rolinski@pik-potsdam.de (S. Rolinski), Lotze-campen@pik-potsdam.de (H. Lotze-Campen), Christoph.Schmitz@pik-potsdam.de (C. Schmitz), Jan.Dietrich@pik-potsdam.de (J.P. Dietrich).

[1] As defined in Falkenmark and Rockström (2004).

http://dx.doi.org/10.1016/j.ecolecon.2014.02.003
0921-8009/© 2014 Elsevier B.V. All rights reserved.

water potentially used in the import countries. These approaches are limited for different reasons. First, they use national average values for water productivity instead of explicit cell based productivities. This becomes especially problematic in large countries with different climatic zones, which relate to different water productivities. Second, calculating virtual water savings by using bilateral trade data, it is not possible to take into account that the landuse pattern and the water usage would change with different production and productivities. Thus, the calculated savings might be flawed. Third, the crop consumption of livestock is not taken into account. When a country is forced to produce the livestock itself, it might need a different amount of crops to feed the livestock, based on a specific conversion efficiency. This again will influence the amount of water used in the crop production. For the estimation of blue and green water savings, an additional problem accrues. These water savings are calculated based on the simplifying assumption that importing and exporting countries produce their crops with the same type of water, which leads to an overestimation of the type of water used in the export countries. Consequentially, estimating blue and green water savings has remained an exception, only de Fraiture et al. (2004) have tried to use this approach to estimate blue water savings for cereals. In fact, the estimation of positive (water saved through trade) and negative (water used for the production of export goods) virtual water savings on grid cell level has not only been assessed by many authors as an inevitable step to avoid biased water flows (Fader et al., 2011; Oki and Kanae, 2004) but even as “not available on global scale” (Islam et al., 2007). Therefore, Oki and Kanae (2004) explicitly state the importance of estimating virtual water transfers on subnational levels. Although some studies have quantified green and blue virtual water flows, it has remained a challenging task to estimate blue and green water savings.

In our study, we estimate blue and green water savings for all agricultural crops on a grid-cell level by extracting the trade-related production and multiplying it with the cell-specific virtual water content. With our model-based (instead of data-based) approach, taking also into account the trade of feed and livestock, we can, for the first time, consistently determine green and blue water savings on grid-cell level, taking into account the difference in the origin of water used in importing and in exporting countries.

When water savings occur in the right places, they can have a decisive impact on local water scarcity. Being the topic of a large body of literature, water scarcity can be measured in different ways. In some studies, total freshwater resources are related to per capita requirements (Falkenmark et al., 1989) or the water withdrawal-to-availability ratio is calculated in order to indicate water scarcity (Alcamo et al., 2003; Hanasaki et al., 2008; Oki and Kanae, 2006; Vörösmarty et al., 2000). Schmitz et al. (2013) developed an agro-economic water scarcity indicator on a spatially explicit level, which is able to quantify the pressure on global water resources. Hoekstra et al. (2012) analyzed the water consumption of river basins, incorporating environmental flow requirements on a monthly basis to assess global water scarcity.

The incorporation of water stress characterisation factors is essential in linking global agricultural consumption to freshwater scarcity (Ridoutt and Pfister, 2010). Several studies have investigated the relationship between water resource availability and virtual water trade. de Fraiture et al. (2004) and Chapagain and Hoekstra (2008) have related trade flows to national water scarcity values. Yang et al. (2003) have linked per capita available water resources with per capita net cereal imports. All of these studies have in common that they base their import and export values, the water scarcity and the water productivities on national statistics. This approach becomes problematic as soon as countries exceed a size where water scarcity and virtual water contents are not homogeneously distributed within these countries. Studies show that in large countries like China and in India, with water rich as well as water scarce regions, virtual water can flow away from water scarce areas (Ma et al., 2006; Verma et al., 2008). Such results could not have been possible by looking at national trade data only.

Recent literature has tried to circumvent the limitation of national data by disaggregating data or by concentrating on specific products or countries. Islam et al. (2007) have investigated the impact of international trade of selected agricultural goods on water availability. The authors disaggregated national virtual water trade data to a subnational level and combined them with grid-based model results on water availability in order to estimate the impact of trade on water consumption. The trade-related water consumption is then combined with the Falkenmark index for six world regions. Ridoutt and Pfister (2010) developed a stress weighted water footprint for two specific products produced in Australia by including the water scarcity of the different production sites. Garrido et al. (2010) estimated an economic scarcity value of the agricultural blue virtual water exports for different regions in Spain by multiplying literature based scarcity values with blue virtual water exports.

In our study we go further than previous studies on virtual water trade and water scarcity. For the first time, we are able to determine on a grid-based subnational level the positive and negative savings of virtual blue and green water through international trade of crops, livestock and feed. In addition, we estimate the impact of trade on blue water resources by combining an economic scarcity indicator with trade related blue water consumption. Since we combine a biophysical water and vegetation model with an economic water and landuse model, we can use consistent information for our analysis and enhance therefore the reliability of our results.

2. Methods and Data

2.1. Model Description of MAgPIE

MAgPIE (“Model of Agricultural Production and its Impact on the Environment”) is a global, spatially explicit, economic landuse model optimizing in a recursive-dynamic mode (Lotze-Campen et al., 2008) (a simplified graphical representation can be found in Fig. 1). The model is implemented in the algebraic modeling language GAMS (Brook et al., 1988) and the programming language R (R. Development Core Team, 2011). The model distinguishes ten world regions on the demand side (Fig. 1) and solves grid-specific (up to 0.5 degree resolution) on the supply side.

With income and population projections (based on the ADAM project (van Vuuren et al., 2009)) as exogenous inputs, required demand is projected in the future and produced by 15 food crops, 5 livestock products, fiber, and fodder as intermediate input (Table 1). Feed requirements for the livestock production activities consist of a mixture of pasture, fodder, and food crops. The livestock-specific requirements depend on not only biological needs for maintenance and growth but also temperature effects and the use of extra energy for grazing (Wirsenius, 2000). The implementation in MAgPIE is described in Weindl et al. (2010). The model simulates time steps of 10 years and uses in each period the optimal land-use pattern from the previous period as initial condition. On the biophysical side, the model is linked to the grid-based dynamic vegetation model LPJmL (description in Section 2.2), which simulates crop yields depending on climatic conditions on a 0.5 degree resolution. In addition to crop yields, LPJmL transfers water inputs, like water availability and requirements per cell and crop, to MAgPIE.

The objective function of MAgPIE minimizes global costs, which involves production costs for the agricultural commodities, technological change costs, land expansion costs and trade and transport costs. There are no explicit irrigation costs, but irrigation renders higher yields and the existence of blue water is therefore a determining factor for the landuse pattern. Irrigation is only possible on areas equipped for irrigation which is implemented based on Döll and Siebert (2000).

Production costs are derived from the GTAP database (Narayanan and Walmsley, 2008) and include factor costs for labor, capital, and