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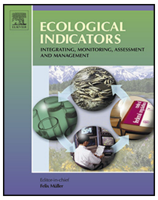

Policy-relevant indicators for semi-arid nations: The water footprint of crop production and supply utilization of Cyprus

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ABSTRACT

The water footprint is an indicator of water use that reveals the inter-linkages between production, trade and consumption patterns. Nevertheless, it has been characterized as a partial tool to be used alongside other indicators and also lacks a temporal analysis in most national and regional assessments. In order to enhance the policy relevance of the water footprint, this paper employs a supply utilization approach related to crop products along with two complementary indicators, namely the economic productivity of crop water use, and a temporally explicit blue water scarcity index. This set of indicators is applied to the semi-arid island of Cyprus over the period 1995–2009. The total water footprint of crop supply (food, feed and other end-uses) was found to be in the range of 1390–2135 Mm^3/year; on average, 13% was blue water and 87% green water. The supply utilization analysis reveals a high green water import dependency, mainly embedded in crops that are destined for feed ingredients. The gross value generated from irrigated cropland justifies the tendency of exporting crops with higher blue water content. However, the scarcity index reveals an unsustainable blue water footprint, which exceeds the natural sustainable supply. Overall, the interplay in the set of indicators examined facilitates an improved understanding of the trade-offs between different policy objectives, while the temporal analysis highlights the importance of assessing national water footprints on a year-to-year basis.

1. Introduction

The water footprint was introduced as an indicator of consumptive water use around a decade ago (Hoekstra, 2003), aspiring to an improved understanding of the production–consumption relationship and the quantification of its associated pressure on water resources. The water footprint represents the latest addition to the “footprint family” (Ewing et al., 2012; Galli et al., 2012), and builds on two key concepts that distinguish it from traditional water use indicators. Firstly, it takes into account “virtual water”, a term coined by Allan (1993), to highlight the redistribution of global water resources due to the intrinsic linkage between water availability, food production and the associated flows of embedded water in traded products. This notion has the potential to alleviate water insecurity and political tension, particularly in water-scarce regions (Allan, 2003). Secondly, it differentiates between the two types of water engaged in biomass production, namely the green (soil moisture in the unsaturated zone originating from precipitation) and blue water (irrigation water originating from surface and groundwater resources), as previously defined by Falkenmark (1995). This blue-green distinction enhances the water footprint analysis since each type of water is associated with a different opportunity cost and environmental impacts.

Blue water is generally considered more valuable since it can be managed and re-allocated to various uses by engineering interventions. However, the conventional management approach that focuses entirely on blue water is seen by many authors as inadequate, as the critical role of green water in sustaining natural ecosystems and ensuring food and water security is not integrated as such in water and land use policies (Yang et al., 2006; Aldaya et al., 2010a). A third component, known as the grey water footprint, has been introduced to account for water quality impairment

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(Chapagain et al., 2006; Hoekstra and Chapagain, 2008) and is defined as the volume of water required to assimilate the pollution load based on predefined quality standards.

Water footprint accounting studies focusing on the agricultural sector have flourished in recent years, for a wide range of spatiotemporal explications. The global study of Mekonnen and Hoekstra (2011) assessed the water footprints of crop products for the period 1996–2005 at a high spatial resolution level, and improved previous global estimates by distinguishing the green, blue and grey components, following several crop-specific studies (Mekonnen and Hoekstra, 2010; Ercin et al., 2012). The water footprint has also been applied at regional (Aldaya et al., 2010b; Vanham et al., 2013a), national (Verma et al., 2009; Ercin et al., 2013) and river-basin scales (Liu et al., 2012; Chen and Chen, 2013), and gained widespread recognition as a water management and climate change adaptation tool (GPPN, 2009), with EU countries like Spain (Aldaya et al., 2010c) and Germany (Flachmann et al., 2012) already employing water footprint estimates in official policy documents.

Despite the appeal of the water footprint concept, several authors have raised concerns about its usefulness (Chenoweth et al., 2013). For instance, Vanham and Bidoglio (2013) note that despite the information provided by water footprint analysis, it is a partial indicator to be used complementarily to other indicators, while Wichelns (2011) points out that it does not take into account water scarcity. Another concern recently expressed in this journal is the oversimplification of water footprint estimates into mean values and the absence of temporal analysis (Finger, 2013); in fact, only a handful of authors examine the evolution of virtual water trade over time (Liu et al., 2007; Garrido et al., 2010; Dalin et al., 2012). Inter-annual variability in water footprints could be regarded, instead, as an important indicator of changing trade and consumption patterns, as well as climatic and land use changes.

In order to generate indicators towards informed policy-making, particularly in the context of semi-arid nations, the present study rests on the following objectives: (a) to explore the blue-green inter-annual variability of crop production, (b) to assess the water footprint related to crop products through a functional supply and use perspective, with specific focus on the internal and external components, (c) to examine the sustainability implications of production and trade decisions using a temporal-explicit blue water scarcity index, and (d) to complement the water footprint analysis by computing the economic value and productivity of crop water use. Cyprus is used as a case-study and the analysis is based on a 15-year period, from 1995 to 2009.

2. Methodology

2.1. Study area

The island of Cyprus is located in the north-eastern Mediterranean Sea. The study refers to the southern part of the country which is governed by the Republic of Cyprus, covering an area of 5760 km^2. Two mountain ranges dominate the island; Troodos in the central-west and Kyrenia in the north. Agricultural fields are scattered in the plain between the two mountain ranges and in the narrow alluvial plains along the coast. With an average annual precipitation of around 460 mm, the climate regime is classified as semi-arid and places Cyprus amongst one of the EU member-states experiencing the highest levels of water scarcity (EEA, 2009). Droughts occur regularly as a result of large inter-annual variations in precipitation that appear to have intensified in recent decades. In particular, the mean annual precipitation has decreased by 14% over the period 1971–2010, compared to the 1901–1970 records (Cyprus Meteorological Service, 2013). Consistent with the robust warming trend in the eastern Mediterranean, drought occurrence is expected to increase in the future as a result of climate change (Hadjinicolaou et al., 2011).

2.2. Methods and data

For the quantification of the water footprint of crop production and supply utilization, the study follows the method based on which commodity balances and supply utilization accounts (SUAs) are prepared (FAO, 2001). This method adopts an identical logic as the bottom-up approach that is typically applied in national water footprint assessments (Hoekstra et al., 2011). However, instead of using only the ‘food’ component of crop SUA as in previous studies (Hoekstra and Mekonnen, 2012), all end-uses are distinguished; for presentation purposes, crops allocated for food and feed are shown separately, while all other end-uses are grouped together (i.e. seed, processing, waste and other utilization). The study focuses on the quantitative aspects of the water footprint, since water scarcity is the primary challenge for semi-arid countries. The major steps of the quantification process are schematically shown in Fig. 1.

The water footprint of crop production refers to the total consumptive green and blue crop water use per year (m^3/year), and was computed using the spatiotemporally explicit soil water balance model developed by Bruggeman et al. (2011). The model follows the FAO-56 dual crop coefficient approach for calculating crop evapotranspiration and scheduling irrigation (Allen et al., 1998), and computes the green and blue water use of 83 crop systems in Cyprus, over the period 1995–2009. The main input data used in the model were annual agricultural statistics and daily climatic and precipitation data. The annual agricultural statistics (i.e. area and production) (Cystat, 1997–2012) were spatially distributed over 431 communities based on agricultural census data (Cystat, 2006), in order to maintain a fine degree of spatiotemporal resolution. Daily climatic and precipitation data were provided by the Cyprus Meteorological Service from a network of 34 meteorological stations and 70 precipitation gauges. Crop parameters were obtained from Allen et al. (1998) and Allen and Pereira (2009), and were adjusted based on local crop management practices. Soil parameters were derived from Hadjiparaskevas (2005) and irrigation systems from Markou and Papadavid (2007). The model and input data are further described in Zoumides et al. (2012).

The quantification of virtual water flows was based on a detailed trade matrix that was provided by the Cyprus Statistical Service. The study covers more than 1400 products based on the 8-digit combined nomenclature (CN) classification; traded products were re-classified to 285 crop commodities and 15 broad crop groups, using international classification standards (FAO, 2005). Following Hoekstra et al. (2011), the internal water footprint was calculated by subtracting virtual water exports from the water footprint of crop production. The external water footprint is equal to the net virtual water imports (i.e. imports minus re-exports), and was calculated using the 1996–2005 weighted average virtual water content of primary crops per country (m^3/ton), as estimated by Mekonnen and Hoekstra (2011). Processed crop products were converted to primary equivalents using country-specific technical conversion factors (FAO, 2003). The origin of virtual water imports was traced in one step; if products are imported from non-producing countries, they were allocated to trade partners based on the weighted annual global average output of the primary crop of origin. The embedded green and blue water in the total water footprint of crop supply per year was allocated to the different end-uses (i.e. food, feed, other), using the available commodity balances and supply utilization accounts, considering annual stock variations (Cystat, 1997–2012; FAOSTAT, 2013).