
Abstract

Many socio-economic and political factors drive food production, consumption, and trade, both locally and globally. The amount of food and agricultural products traded on the global market has doubled in the last 20 years; therefore, political boundaries do not coincide with the resources needed to sustain their own population. Some countries do not cultivate enough food to meet their needs and depend on imports to maintain food security. In contrast, others produce more than they need and turn to export-oriented activities to meet international demand for certain goods. Still, other countries may also reduce the domestic production of some goods to import them from abroad at a lower price, or sell abroad rather than domestically because this strategy allows them to gain larger profits.

Water plays a key role among the natural resources most commonly used in food production processes, and the notion of "virtual water" plays an essential role in shedding light on the movements throughout the water-food nexus. The virtual water content of a certain commodity is defined as the total volume of water required to produce it. It depends both on production conditions and on the efficiency and performance of irrigation systems. Therefore, what is traded on the international market are not just commodities, but also the water resources exploited during their production. Consequently, the availability of water resources has great influence on the competitiveness of a country on the international market, as well as on its own internal production capabilities. However, the trends recorded during the recent intensification of international trade have led to a growing disconnect between consumer demand for goods and services, and the intrinsic water value that these goods embed as a result of their production process.

This thesis investigates the water-food nexus from an economic perspective, exploring aspects of both food production and the related international virtual water trade. In particular, we aim to delve into the following issues: (i) within the water-price debate, we analyze whether agricultural commodity prices reflect the value of the water required to produce them; (ii) at the government policy level, we examine on a global scale the relationship between trade agreements and the topology of the agricultural trade network, investigating in terms of water productivity the differences between flows covered by trade agreements and those not covered; (iii) at the regional scale,

through a simulation tool (the MAGNET model), we investigate the future developments of African virtual water flows and the effects of implementing the African Continental Free Trade Area (AfCFTA) on the African virtual water network; (iv) we develop an integrated communication strategy to outreach the people outside academy. More in detail:

(i) market dynamics can be associated with production and export choices, as well as with the price of agricultural products. In the continuing debate on whether water should be assigned an economic value, the question of whether water is reflected in the market prices of goods has not been fully addressed. Therefore, we investigate the relationship between water consumed in agricultural production and crop prices. In particular, we explore the relationship between farm gate prices and two environmental resources used in agricultural production: harvested area per tonne (land footprint) and water per tonne (water footprint). Initially, we focus on the relationship between crop water consumption in terms of water footprint and crop prices, finding a positive and statistically significant relationship. However, the literature argues that the value of water can be inextricably embedded in the value of land; both the size and regularity of food production depend on the presence of water in the land. Therefore, we analyze the water footprint in its two components: soil footprint and evapotranspiration. We find that the relationship between water footprint and crop prices is not fully incorporated in the role played by harvested area; the water component, in terms of evapotranspiration, seems to be correlated with price behavior, independently of the land footprint. The results illustrate an interesting aspect: paradoxically, only the prices of relatively less water-intensive goods show significant relationships with the water footprint of production; this allows us to hypothesize that different production and marketing structures influence the inputs taken into account in market prices. In fact, staple crops are often sold in competitive markets, where the amount of water used during production is positively associated with the crop price. In contrast, fewer producers grow cash crops and set prices according to international market factors;

(ii) as mentioned, the volume of agricultural products traded on the global market has multiplied in recent decades. In this scenario, governments play a crucial role at the policy level by establishing international agreements, thus defining the global market. We investigate the impact of trade agreements on the trade network of agricultural products to identify the relationships between market liberalization and food flows. In particular, we study whether the ratification of agricultural-oriented trade agreements

is associated with changes in the food trade network (link establishment) and with flow increases through existing links. We find that implementing trade agreements tends to correlate with establishing new links and with commercial relationship persistence when two countries are already trading. First, the presence of a trade agreement shows a higher likelihood of continuing a commercial relationship over time. Second, compared to trade relationships not covered by the agreement, flows covered by trade agreements present higher flow values in both years with smaller inter-annual average flow variations. Moreover, from an environmental point of view, flows under trade agreements reveal higher economic (US\$/m³) and nutritional (kcal/m³) water productivity. Therefore, trade openness seems to promote higher water efficiency.

(iii) the African continent faces water scarcity problems, and the agricultural sector consumes much of the continent's water. Moreover, agricultural food trade triggers exchanges that transfer water resources to countries far from production. Based on these assumptions, we study the future developments of African virtual water flows and the effects of implementing the African Continental Free Trade Area (AfCFTA) on the virtual water network involving the African continent. Using the detailed virtual water production and trade matrices developed within the CWASI (Coping with water scarcity in a globalized world) project, we translate dollar projections obtained with MAGNET (Modular Applied GeNeral Equilibrium Tool) into virtual water. This dollar-to-water conversion allows us to capture production and trade projections in 2030 for a baseline scenario and an AfCFTA scenario removing tariff barriers. We then find that the base case projections to 2030 show significant increases in African production, especially in exports in extra-continental trade (51%) and intra-continental trade (34%). The implementation of the AfCFTA has the impact of reducing extra-continental exports almost in proportion to the increase in intra-continental trade. We also analyze the effect on virtual water of African economic regions and agricultural sectors to investigate whether the projected increases depend on region-specific or crop-specific factors.

(iv) All the studies described in this thesis are part of the European CWASI (Coping with water scarcity in a globalized world) project, founded by the European Council. In the last section of this work we discuss the dissemination strategies and communication framework created by our research group to successfully spread out five year of scientific research on the theme of water. During the CWASI project, we understood that the water-food nexus, and studies related to this concept, incorporate sub-

stantial environmental, economical and social dynamics. These dynamics and what we learned about them, have a huge influence on the contemporary world and society, and we felt it was necessary to maximise the chances to make these notions available for a wider and non-specialized audience. With our communication project, called WaterToFood, we create a multimedia platform to fulfill these goals, thanks to videos, an interactive online database, a curated magazine and constant social media coverage.

All in all, the common thread of this work is to analyse and interpret dynamics relative to water-footprint and virtual water using a multidisciplinary approach. The fulcrum is represented by the economic processes that lie behind the water-food nexus and its constant motion, but great importance is also given to the responsibilities that scientific research has toward society while disseminating its results.