Abstract

In the past century, global water consumption increased nearly 8 times and over the last decades the rate of demand for water has exceeded twice the rate of population growth. Nowadays, the agriculture sector is by far the largest freshwater-consuming human activity on Earth accounting for nearly 70% of the total withdrawal and around 90% of the total water consumption. Moreover, the agriculture's "thirst" is expected to persistently rise in the next years, due to the growth of the world population, the rising of living standards and climate changes. This pressing human demand for water is causing remarkable environmental impacts, in particular on surface water resources that globally contribute about 60% of the total water used for irrigation. Today, freshwaters are recognized has the most extensively altered ecosystems on Earth by the human intervention. Therefore, fulfilling the competing water requirements of ecosystems and societies is a key global environmental challenge for our time.

Globally, about a quarter of the food produced for human consumption is traded internationally and several countries significantly depend on imported commodities. It follows that an important part of the world population relies on external water resources and impacts external freshwater ecosystems. In this context, the concept of "virtual water" has played an essential role in shedding light on the links between the food consumption geography and the water resources exploited. However, virtual water assessments typically aggregate and compare water volumes without taking into account the place where water has been actually withdrawn (e.g., without differentiating between water-abundant and water scarce regions). As a matter of fact, the uneven distribution of surface water resources implies that the withdrawal of a same volume of water can have very different environmental consequences in different riverine ecosystems.

In this context the Thesis aims (i) to develop an approach able to support the interpretation of the volumetric measure of surface water withdrawal by adopting an impact-oriented perspective, thus considering the environmental aspects of the freshwater ecosystem where the withdrawal actually occurs; (ii) to quan-

tify the environmental impact of food consumption on local and foreign water resources and to understand the role of the food globalization on world's rivers; (iii) to identify the major socio-economic determinants behind the growing use of foreign (and domestic) freshwater resources.

In order to address the first aim, this Thesis defines a novel indicator – named Environmental Cost index - to assess the environmental impact of a withdrawal from a generic river section. The index depends on (i) the environmental relevance of the impacted fluvial ecosystem (e.g., bed-load transport capacity, width of the riparian belt, biodiversity richness) and (ii) the downstream river network affected by the water withdrawal. The index is referred to a potential reference withdrawal that can occur in any river section of the world's hydrographic network. Being referred to a potential unitary withdrawal that can occur in any river section worldwide, the results can be suitably arranged for describing any scenario of surface water consumption (i.e., as the superposition of the actual pattern of withdrawals). Our results highlights the river regions where water withdrawals can cause higher environmental costs. In addition, the approach defined in this Thesis is an easy-to-apply tool to identify the most impacting water consumption patterns on the hydrographic network.

Building on the aforementioned definition of Environmental Cost, we quantify the environmental value of the riverine water (EVRW) embedded in food products. Through this measure we explore the role of food production and trade on the world's riverine ecosystems unveiling a novel facet of the food-water nexus. In this Thesis, we describe the geography of country (or individual) responsibility on the environmental changes of world's rivers. We show globalization drives an international trade of environmental value of surface water and local threats to fluvial ecosystems are induced by the food demands across the globe. Hotspots of food-related river-environment degradation are found in Australia, Pakistan, South Africa, and Spain. Globally, between 1986 and 2013 food consumption has more than doubled its impact on foreign riverine environments, but still the international trade reduces the pressure of food consumption on global river system by 11%, as compared to an ideal situation where all food is produced locally.

As mentioned, the recent intensification of international trade has led to a growing disconnection between the consumers demand for goods and services and the water resources that support them. However, despite the important role of the consumers demands on the exploitation of distant freshwater resources is widely recognized, the different socio-economic drivers behind the trends in domestic and foreign freshwater use remain poorly quantified. In this Thesis, the main mechanisms governing the exploitation of domestic and foreign water resources are quantified by undertaking a structural decomposition analysis over the $1994-2010$ period in 186 countries. Results show that the affluence growth has been the main determinant of rising water consumption trends worldwide. Consumers in developed countries tend to increase their affluence by intensifying the use of foreign freshwater resources; conversely, the affluence growth in developing regions mostly relies on the exploitation of local water resources revealing a significant imbalance among economies. The affluence and the demographic growth have been only partially offset by improvements in the blue water efficiency of producers and, to a lesser extent, by changes in production technology.