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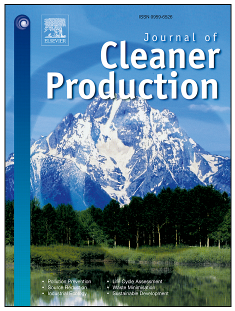

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Downscaling the grey water footprints of production and consumption

Abstract

While economic and environmental policies and strategies are largely designed at the international, national or regional level, the environmental impacts of these measures are often felt at a more geographically-localized level. In particular, the effects on water resources, especially regarding water pollution and water stress, are usually localized in very specific hotspots. In this work, we acknowledge these facts and attempt to identify the linkages among the 17 regions in Spain (a semi-arid country with significant geographical variations in water availability), the European Union (EU), and the Rest of the World (RW), while also looking at the local effects of those interactions. In particular, we study the grey water footprints (a measure of the assimilation capacity of water resources) of production, at both the regional and business level, with spatially explicit information, and the extension of those footprints throughout the supply chain, while also computing the water footprints of consumption at the regional level. This process is a combination of a detailed computation of grey water footprints from production, from agriculture (from diffuse pollution), and from more general economic activities (from point source pollution), with a multiregional input-output model that encompasses the 17 Spanish Regions, the EU, and the RW. We also identify hotspots and vulnerable areas, linking the grey water footprints from production originating in these areas to final-consumer responsibilities. As an example of the potential of the combined methodology, we design and evaluate the effects on grey water footprints of scenarios of import substitutions in Spain. Our results show strong final demand in regions such as Madrid and Catalonia, and in net exporting regions such as Andalusia, Aragon, Castile and Leon, Castile-La Mancha, Extremadura, and Navarre. Some of these regions contain areas that are clearly vulnerable to nitrates and other pollutants, and parts of these regions, most obviously in Andalusia and Extremadura, suffer water stress, which leads us to question the sustainability of the relationships between the structure of production and trade and the environment.

Keywords: grey water footprints, downscaling, regional science, input-output, GIS, Spain.

Abbreviations: VW, Virtual Water; GVW, Grey Virtual Water; WF, Water Footprint; MRIO, Multi-Regional Input-Output; IO, Input-Output; GIS, Geographic Information Systems; GWF, Grey Water Footprint; N, Nitrogen; AR, Autonomous Regions; RS, Rest of Spain; EU; European Union; RW, Rest of the World; Supplementary Information (SI).

1 Introduction

Water pollutants can lead to disruption of the food chain, and can spread disease among animals and humans,, not to mention such environmental effects as alteration of, and damage to ecosystems[1]. A general overview of the pollutant levels in Spain, compared to other European countries (EEA, 2014), shows relatively high concentrations of nitrates on the Mediterranean coast and in the south of Spain, of phosphorus on the Mediterranean and Cantabrian coasts (due to phosphate fertilizers, livestock residues, and the mining industry), and biological oxygen demand (BOD) in the north and in specific areas of the far south (with similar worrying levels in southern Italy and Romania). The concentration of nitrates in rivers in Spain is, in general, not as high as in the north of France, the southern UK, Germany, and western Poland, but in certain agricultural areas of Spain the concentration is a concern. All in all, a worrying, general qualitative assessment was provided by Greenpeace (Greenpeace, 2005), claiming that only 11 % of surface water and 16% of groundwater meets the acceptable conditions of the environmental objectives of the European Water Framework Directive (EU, 2000). In Spain there is a limitation on Nitrates to comply with the national and European maximum target of 50mg/liter, but only an indirect limitation of phosphorus[2] in manure applied in Nitrate Vulnerable Zones (Amery and Schoumans, 2014).

The Grey water footprint (GWF) from production, the focus of this paper, refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards. The volumes obtained for the GWF are a measure of the pressure imposed, mostly through economic activities, on water resources in a region that, especially compared to the water availability in the region, results in a significant environmental indicator. In this article, we examine these and related measures for the 17 Spanish autonomous regions (AR from here on) through a multi-regional input-output (MRIO) model that also includes the regions of the European Union (EU) and the Rest of the World (RW), combined with detailed GIS (Geographic Information Systems, for the specification of impacts) data and tools. These tools allow us to address a major, and growing, concern of the past decade in the field of economics and environmental studies,

[1] Phosphorus (P) is the major contributing factor in the process of eutrophication. Inputs of phosphorus come from erosion, fertilizers, detergents, and the draining of wetlands. Nitrogen (N) is a much more abundant element in nature, and is an important plant nutrient, often used as a fertilizer. It is also found in high concentrations in agricultural runoff and contributes to the eutrophication of lakes and streams. Biological oxygen demand (BOD) is a measure of the oxygen in the water that is required by aquatic life (as a rule, measured after five days, BOD5, at room temperature). Rivers with high BOD have high nutrient levels in the water and most of the oxygen is consumed by the organisms. The chemical oxygen demand (COD) test is also commonly used to indirectly measure the amount of organic compounds in water, as a water quality measure (expressed in milligrams per liter, indicating the mass of oxygen consumed per liter of solution). Finally, other common water pollutants we will focus on are Total suspended solids (TSS), a water quality measurement indicating the amount of solids in suspension; and heavy metals (metal or metalloid), also of clear environmental concern.

[2] Except for the Extremadura region: a limit of 80 kg P2O5/ha/per year for olives, rice, tobacco, and deciduous fruit trees.

the analysis of embedded or virtual flows and footprints, driven by a particular interest in understanding and reducing human impacts on the planet.

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The rest of the paper is organized as follows. Section 2 reviews the existing literature on water footprints, and on national or multi-regional models of water. The methodology and data necessary to construct the model are briefly described in Section 3. Section 4 discusses the results of flows and regional GWF, and Section 5 presents our conclusions and discusses certain policy implications.

2 Background

From a new and different thread of research than the early works that computed "embodied" or "embedded" water volumes such as (Lofting and McGauhey, 1968) using input-output analysis, two concepts have notably gained in importance in the 21st century. The concept of virtual water (VW), defined -as the volume of water required to produce a given item (Allan, 1993, 1994, 1998) and the water footprint (WF), used to measure the human appropriation of volumes needed for human consumption (Chapagain and Hoekstra, 2004; Hoekstra and Chapagain, 2007; Hoekstra et al., 2009, 2011; Hoekstra and Hung, 2002). Proof of that, together with the wide dissemination of these studies and of those estimating or comparing global flows of virtual water (Chapagain and Hoekstra, 2003; De Fraiture et al., 2004; Oki et al., 2003; Zimmer and Renault, 2003), was the creation of the *Water Footprint Network*, the systematization of concepts and definitions, and the introduction of the *Water Footprint Manual* to gather the state of the art. There has been a proliferation of research in this area, notably on green and blue water footprint estimates, although not so much, as yet, on Grey Water Footprints (GWF)[3]. Concerns about resource scarcity and the high impacts on global water resources have been studied in the context of international WFs in a range of studies (Chapagain and Hoekstra, 2003, 2004; Hoekstra and Chapagain, 2007) and work has been done related to other impact assessments for water use in the life cycle (Jeswani and Azapagic, 2011). Only a few papers have studied the theory and application of GWF and water pollution globally (Chapagain and Hoekstra, 2008; Franke et al., 2013; Hoekstra and Chapagain, 2007; Hubacek et al., 2009; Liu et al., 2012), or locally (Wang et al., 2013).

In recent years, a number of MRIO models have been constructed to assess environmental pressures (emissions) from trade, or associated with consumption. See (Wiedmann et al., 2007) and (Wiedmann, 2009) for a review. For the study of water flows, inter-regional or multi-regional IO models have examined impacts across regions of China (Feng et al., 2012; Guan and Hubacek, 2007; Jiang et al., 2015; Okadera et al., 2006), Australia (Lenzen,

[3] Green water is that portion of precipitation that is initially in the unsaturated zone of the soil and therefore does not leach into aquifers or become part of surface runoff. Blue water is the part that directly or indirectly ends up as surface flows.

2008, 2009), Mexico (López-Morales and Duchin, 2011) the UK (Allan et al., 2004), (Wiedmann et al., 2010), Spain (Cazcarro et al., 2013), and globally (Lenzen et al., 2013b).
Most of these papers focus on volumes of green and blue water, and in general they have the advantages of accounting for the entire supply chain of production, among sectors - especially industrial and services- in different regions or countries. As is often the case, we note the usual disadvantages with respect to other process-analysis methods: the lack of agricultural detail, a lower degree of homogeneity in the assumptions chosen (e.g. on the treatment of imports) and/or the absence of estimates on GWF from production and consumption. Several papers (Daniels et al., 2011; Duarte and Yang, 2011; Ewing et al., 2012; Kitzes, 2013) provide further insights into the methodologies of water and environmentally-extended IO analysis, and their strengths and weaknesses.
There have been studies specifically focused on Spain as a whole, or on its regions, focusing on agricultural production chains (Garrido et al., 2010), and on IO techniques (Dietzenbacher and Velazquez, 2007; Duarte et al., 2002). We also find works dealing with GWF or with water pollution in Spain for specific products (Chico et al., 2013; Salmoral et al., 2011), and with input-output techniques (Sánchez-Chóliz and Duarte, 2003, 2005), although these studies are conducted in a single region, and with less sectoral detail. To the best of our knowledge, no prior analyses of GWF have been developed in Spain in the context of an MRIO database and model. Furthermore, none connect the meso-level scale to the specific business level and local hotspot identification, which GIS databases provide.

GIS have played an evolving role in planning, socio-economic, and environmental analyses (Malczewski, 2004), but the intersectoral and interregional links across entire supply chains, that connect the production with the consumption side, cannot be captured only through a pure spatial representation of impacts. The combination of tools and models that we follow here allows us to examine meso- or macro- policies, through intersectoral and interregional relationships, and their effect on local hotspots and water areas, something which could not be performed with only MRIO or only GIS tools.

This work is one of the first attempts to combine MRIO with GIS analysis. It has been recently analyzed or applied by (Hubacek and Sun, 2001), implementing in GIS the biophysical attributes of land, and demographic data at the county level, to assess how different development paths influence the available land and trade flows of primary products. (Albino et al., 2007) combine the tools based on IO and specific processes to represent and describe the logistic flows of an industrial supply chain. Another interface with multisectoral models is (Haddad and Teixeira, 2013), examining the regional economic impact of natural disasters in the megacity of São Paulo with a spatial CGE model, and GIS information on floods and firms within their influence. A somewhat similar approach is being developed, based on the concepts of the "mother table" and Virtual Laboratories, for spatial and sectoral detail of meaningful environmental footprints and LCA applications (Lenzen et al., 2013a; Wiedmann et al., 2013). As a novelty, our work combines these tools and models with an MRIO framework and for a particularly localized environmental topic, GWF of production, with an interface that allows the automatic analysis of the local effects of a policy defined at a higher decision level.

3 Methodology and Data Sources

MRIO and GWF from production estimates at the regional and business levels

Our starting point is an MRIO model constructed on the basis of the regional Spanish IO tables - distinguishing domestic production and imports by origin, the Rest of Spain (RS), the EU and the RW - published by the Statistical agencies in each region. We choose 2005 as reference year because it is the year for which most of the regional tables are provided. Trade between regions is broken down using the structural database C-INTEREG. The statistical proceeding to obtain the full multi-regional tables can be seen at (Cazcarro et al., 2013).

The MRIO model has 19 regions corresponding to the 17 Spanish ARs (which we will designate with subscripts $i = 1,\ldots,17$, and two other regions, EU and RW (i= 18 and 19). It is based on the interregional and multiregional models of (Chenery, 1953; Isard, 1951; Miller and Blair, 2009; Moses, 1955), with the equilibrium equation (1) being:

$$\mathbf{X}^{\oplus} = \mathbf{A}^{\oplus}\mathbf{X}^{\oplus} + \mathbf{Y}^{\oplus} \Leftrightarrow \mathbf{X}^{\oplus} = \left(\mathbf{I} - \mathbf{A}^{\oplus}\right)^{-1}\mathbf{Y}^{\oplus} = \mathbf{L}^{\oplus}\mathbf{Y}^{\oplus} \quad (1)$$

Where $\mathbf{A}^{\oplus}$ is the multi-regional matrix of technical coefficients, $\mathbf{L}^{\oplus}$ its Leontief inverse, $\mathbf{X}^{\oplus}$ is the output matrix and $\mathbf{Y}^{\oplus}$ is the final demands matrix.

In $\mathbf{A}^{\oplus}$, each 40x40 matrix $\mathbf{A}_{rr}$ indicates the domestic technical coefficients in region *r*. The 40x40 off-diagonal matrices $\mathbf{A}_{rs}$ indicate the coefficients of region *s* of imported inputs from *r*. Each element a_{rs}^{ij} of the matrix $\mathbf{A}^{\oplus}$ expresses the quantity of output of sector *i* produced in *r* and consumed as input by sector *j* of region *s*, per unit of total output of sector *j* in *s*.

Matrix $\mathbf{Y}^{\oplus}$ is formed of 19 column vectors $\mathbf{y}_s$ with vector $\mathbf{y}_{ss}$ (40x1) representing the domestic final demand of *s*, and with the other $\mathbf{y}_{rs}$ being the final demands of goods from *r* to *s* not consumed as productive inputs, i.e., the flows of finished products from *r* to *s*.

Matrix $\mathbf{X}^{\oplus}$ is formed of 19 column vectors $\mathbf{x}_s$ each of which represents, according to (1), the production needed to obtain final demand $\mathbf{y}_s$. This production can be broken down into $\mathbf{x}_{ss}$ (a 40x1 vector), which is the production of *s* used to fulfil the final demand $\mathbf{y}_s$, and vectors $\mathbf{x}_{rs}$ which quantify the additional production needed from the other regions *r*.

We obtain the grey water flows and footprints, in a similar way to the green and blue VW flows and footprints in (Cazcarro et al., 2013). Diagonalizing each of these vectors to obtain $\mathbf{Y}^{\oplus +}$, and making use of $\hat{\mathbf{w}}^{\oplus}$, the matrix of the diagonalized grey water footprint of production coefficients (grey water footprint of production per unit of economic output), we obtain $\mathbf{H}^{\oplus}$, with each of the three elements in the following equation having dimension of 760x760.

$$\mathbf{H}^{\oplus} = \hat{\mathbf{w}}^{\oplus}\mathbf{L}^{\oplus}\mathbf{Y}^{\oplus +} \quad (2)$$

Empirically, our first objective is to estimate $\mathbf{H}_{r,s}$ a double-entry matrix showing the grey virtual water flows from region *r* to region *s*, and to identify the different components presented above.

Each $\mathbf{H}_{r,s}$ (40x40) is then a matrix showing the grey virtual water flows from region *r* to region *s* (whose elements h_{rs}^{ij} represent, in input-output terminology, the direct and indirect embodied grey water to meet the demands of sector *j* in region *s* from sectors *i* of region *r*). For each region, we obtain the GWF, and we consider 40 economic sectors/products, obtaining the VW contents in trade for each of them.

The estimates of the GWF from production are obtained and assigned at the business level, but the process of estimation departs from those GWF at the regional level, which are then combined with the information at catchment and business levels.

The integration of the MRIO and GIS

Most environmental input–output analyses have addressed questions at the macro- or meso-level of economic activity, accounting for environmental impacts at the country or regional level, or have considered the behavior of individual or grouped sectors of an economy. However, when we need to analyze the use of very localized resources (such as water) or the environmental impact of an economy in highly localized pollutants, the regional approach may be insufficient for accurate risk assessment and, in consequence, for the evaluation of water management policies.

Economic input-output (IO) data can only rarely be easily localized in greater detail than the national or regional accounts compiled by national or regional statistical institutes, which is the level at which major meso- and macro-economic policies take place. Thus, although considering the inter-regional flows at the regional level, we can also combine this information with spatially explicit information on polluting activities. An important point in this article is the combination of IO (economic) and GIS (geographical specification of impacts) models. This is done by implementing in the Model Builder of the ArcGIS software the script with the bidirectional relationship of the MRIO at the level of regions, with the GIS layers[4] (regions, municipalities, villages, businesses and their specific emissions to water, basins, rivers, water masses, vulnerable and sensitive areas data) and tools (Spatial join, layer overlapping/intersection/resampling/queries, Arc Hydro, kriging, etc.) of the software itself. The main relation from the specific layers to the MRIO is the simple aggregation of data or spatial join to the regional level of the MRIO, while the disaggregation of regional data or results from the MRIO (e.g. changes in grey water footprint by sector and region) is performed with the script of apportioning them to the layer (e.g. businesses) according to criteria ranked by priority. (For example, if available, the share of the business in the sector and region of its emission to water; otherwise the share

[4] It is important to understand that the modification of the layers implies a modification in their .dbf file, which contains feature attributes with one record per feature.

in the non-identified sector and region of its income; otherwise based on the statistical/spatial relationships found in the statistical analysis, etc.).

Further details of the MRIO and the GWF and estimates of related variables are provided in the Supplementary Information (SI).

4. Results

4.1. Downscaling direct water pollution at origin and GWF

The main statistics regarding the database, and the distribution of direct grey water, according the criteria above, are summarized in Table S1 and graphically in Map S2 in the SI, showing the geographical distributions according to the size of the enterprises of the different regions. Important concentrations of business, economic activity, and GWF from production can be observed on the east coast of Catalonia and in Valencia, as well as along the Ebro (northeast) and Guadalquivir (southwest) rivers. Map S2 focuses on the distribution of GWF from production associated with industrial and services activities. However, as introduced above, major non-point-source pollution occurs due to excessive or incorrect applications of nitrogen fertilizers in agriculture. Accordingly, the complete picture of GWF from production, i.e., from agriculture, industry, and services, identified by business and land-cover type (Büttner et al., 2004; Büttner and Kosztra, 2007; EEA, 1992) is shown in Map 1.

(Insert Map 1)

Increased agriculture - especially livestock production and modernization - associated with intensification and increased farm size, have led in principle to greater efficiencies and productivity, but involve potential risks to the environment. In particular (together with global warming from methane and nitrous oxide), a significant risk of water pollution due to livestock intensification may come from nitrates, from percolation through the soil of inorganic nitrogen, and ammonia emissions linked to acidification and eutrophication. In a departure from Map S2, the size of the spheres in Map 1 also classifies grey water volumes. The map clearly shows the characteristics of GWF from production in Spain. On the one hand, very limited areas (in red) with significant impacts are located in the vicinity of the largest industrial cities (Barcelona, Madrid and their areas of influence, and nearby areas of Castile-La Mancha, where the *Tablas de Daimiel* wetland has decreased from 20 to 1 km^2 in 30 years), and areas of important agricultural density along the Duero river (notably near Segovia and Valladolid, in the region of Castile and Leon) and the mouth of the Guadalquivir river (in Andalusia). Moreover, there are broad tracts with more diffuse, but significant, GWF from production (orange areas). In this case, areas of Castile and Leon (near Salamanca and Segovia, affecting the Arenales aquifer, one of the largest in Spain), Andalusia, Aragon, and Valencia stand out.

One of the interesting possibilities of our analysis is to relate the GWF from production to the potential renewable[5] water resources in each geographical area. Map 2 plots the Spanish areas according to values of grey water to PRWR ratio. Intense grey (WF of production per PRWR ratio) regions are Madrid, the Canary islands (with an important disrupted aquifer) and Ceuta and Melilla, along with the Mediterranean coast, especially the regions of Catalonia (with the paradigmatic high pollution level of the Flix reservoir in the Ebro valley, which serves about a million people, irrigates 50,000 hectares of crops, and nourishes the Ebro Delta protected space), and Valencia (where the Albufera suffers constant "aggression" wastewater from the capital of the province).

(Insert Map 2)

This picture allows us to identify areas vulnerable to nitrates[6] (MMA, 2013) in water pollution. In order to reduce and prevent future water pollution by nitrates from agricultural sources, the 91/676/EEC Directive was developed. Its implementation requires the definition of the areas affected by pollution by nitrates, and other vulnerable areas. Affected areas are declared to be those with excessive groundwater or surface withdrawals, or those that exceed nitrate concentrations of 50 mg/l, and reservoirs, lakes, ponds, estuaries and coastal waters that are, or could be, in a state of eutrophication. Plots of land whose runoff or seepage can influence the state of the waters affected are designated as vulnerable zones.

The vulnerable areas appear in white and red, mainly located around the largest conurbations in the country, the area of Madrid (although extensive areas are also located in Castile-La Mancha, in a continuation of the vulnerable areas of the southeast of Madrid), and the interior of Barcelona/Lleida. Other important vulnerable areas are the lower reaches of the Guadalquivir river (through most of Andalusia, and mainly through Seville), the areas around the city of Zaragoza, on the Ebro river (and hence its catchment), around Valencia (in the Valencian community/Júcar catchment) and some areas of the Balearic Islands (specifically Mallorca).

Additionally, Map 2 is completed with a first simple representation of the distribution of GWF in the territory, with the circles plotted in red according to the size of the cities, showing the levels of the GWF from consumption. These depictions closely follow the pattern of population distribution, despite the income per-capita differences among regions.

Finally, also observed by catchment in Map S3 in the SI, the ratio of grey water to natural water availability shows the Segura river catchment (mainly in Murcia) in a more intense grey colour, more than in any other region, followed by the catchments/regions of the

[5] The Potential Renewable Water Resources (PRWR) refers to the previous Natural water resources, less restrictions (environmental reserve or international transfers), counting transfers and the reuse and desalination capabilities. When natural water availability is taken into account, the region of Castile-La Mancha appears to have no problems of grey water production to availability ratio (almost White, as the group of Galicia, Asturias and Cantabria), while Murcia jumps one scale and appears in a more intense grey colour.

[6] The zones vulnerable to nitrates are those defined in accordance with Directive 91/676/EEC, concerning the protection of waters against pollution by nitrates (that exceed, or are likely to exceed, a concentration of nitrates 50 mg/l. The land whose runoff or leakage may influence the condition of the waters affected are called vulnerable areas.

Mediterranean coast. The effect of Madrid becomes diffused (less intense grey than when only regions are considered) with respect to the whole Tajo catchment.

4.2. Aggregated regional GVW and GWF

The results presented above identify geographic areas with large GWF. The traditional predominance of agriculture in describing blue and green WF is now (when accounting only for grey WF) moderated, giving more importance to areas with significant industrial activity. This would be more noticeable if even more industrial (chemicals, etc.) impact data were available, to account for the GWF or some combination of the effects of their presence were considered. The question that arises, now that we have identified geographically the main areas of high GWF from production and consumption, are what factors explain this distribution. In other words, how are the different regions and sectors related, what factors are most important, and what are the destinations of the production and GWF of production generated in these regions? Tables 1 and 2, and Map 3 summarize GVW flows among regions based on the MRIO.

(Insert Table 1)

(Insert Table 2)

(Insert Map 3)

As can be seen in Table 1, 21 of the 83 km^3 of GWF of consumption of Spanish regions come from other countries. Within Spain, Andalusia, Castile and Leon, Castile-La Mancha, Catalonia, and Valencia are the regions with the greater volume of GWF from production, with over 60% of all GWF from production in Spain. However, the behavior of these regions is very different, when we look at trade and GVW flows, and at the geographical distribution (at the origin) of the GWF from production. In Andalusia and Catalonia almost half of the GWF from production is internal, (from goods and services ultimately consumed by its own citizens), Castile and Leon and Castile-La Mancha are regions where GWF from production is largely from inputs from the rest of Spain. This is also seen in other regions, such as Aragon and Navarre, which generate about half of their GWF from production from sales to the rest of Spain, and an additional 20% from sales abroad. Valencia generates GWF from production almost equally in the production of domestic goods (internal water footprint from regional consumption), in the production of goods to the rest of Spain, and in the production of goods to the rest of the World. The differences are also due to the types of specialization.

Regional shares in the Spanish GWF from production are clearly related to the industrial concentration and specialization in activities of the chemical industry, heavy metals, energy, and food transformation. This is the case of Catalonia (11% of the grey WF share), Valencia (10%), Madrid (7%), and also clearly in regions with smaller absolute numbers such as the Basque country (3.0%), Asturias (2.2%) and Cantabria (1.5%). In the case of the Canary Islands (3.8%) and Balearic islands (1.7%) tourism and related activities also come into play.

Looking at the GWF from consumption, the most populated areas of Spain, with the highest regional income (Madrid, Catalonia, Andalusia, and Valencia), can be identified as the main driver hubs in the generation of GWF from production in other Spanish regions. These regions then have particularly high external GWF from their regional consumption, coming from grey VW imports of goods and services produced in other Spanish regions. In the case of Andalusia, it is clearly driven by absolute but also high population size relative to other regions. In the case of Madrid, Catalonia, and to some extent Valencia, the high GWF from consumption is driven by a high per capita income.

Table 2 and Map 3 allow us to be more specific in this, as well as in identifying the GVW flows (hm^3) among Spanish AR, finding in the last column of Table 2 their net exporter or net importer character.

Thus, we can see that Madrid, Catalonia, the Basque Country, Murcia, and the Canary Islands, as well as the EU, are net importers of grey water, avoiding the generation of additional impacts on their territory through purchases from other regions of Spain. By contrast, regions such as Andalusia, Aragon, Castile-La Mancha, Castile and Leon, and Valencia appear as major suppliers of inputs to these regions. The character of exporter or net importer of GVW reflects, in a way, the extent to which integration of the region with its neighbours (RS, EU, or RW), conditions its production and therefore, its environmental impact. A net importer is a region that mitigates additional pressure on local resources through the import of goods from other parts of the country, or of the world. This takes on a special character when relating these findings to the data on water availability in the territory.
Map 3 also shows that Madrid is likely the region with the greatest water scarcity (on the map, dark grey, almost black), measured by the GWF required for production in the region, in relation to the availability. Looking at Table 2 and Map 3, we can also see the specific flows between regions, with the largest export flows of GVW (embodied) from Castile and Leon and Castile-La Mancha to Madrid. Other major flows are found from Aragon to Catalonia, and some relatively significant GVW flows from Navarra to Catalonia, the Basque Country, and Madrid.
Murcia is a net importer of GVW, receiving it mainly from Andalusia, Castile and Leon, and Valencia; its exports to the EU and RW are also important. Moreover, its high GWF from production, in relation to water availability, is due to the high concentration of fertilizer products in the agricultural sector, especially phosphorus and nitrogen, which percolate into water resources whose volumes are insufficient for dilution, and also because of heavy metals such as chromium, lead, mercury, and selenium. Finally, Andalusia and Extremadura are also exporting GVW, having significant direct and indirect impacts on water from agricultural exports. They also have strong industrial imports, whose weights in the GWF from production are more important than in green or blue WFs from production.

Something similar to what happens in many Spanish regions also happens in the EU, which is also a net importer of grey water (see Table 2). By contrast, the rest of the world is a net exporter. Overall, Spain makes a net import of grey water.

Regarding the sectoral composition of grey water flows, Table S2 shows the importance of the embodied grey water content of agriculture, the food industry, and restaurant activities, in addition to significant values coming from Textile, clothing and leather, Construction, Manufacture of motor vehicles and other transport equipment, energy extraction and distribution, Public Administration or Health, sanitation, and social services. We also see important numbers for Restaurants in Andalusia, Catalonia, Madrid, and Valencia, for Agriculture, hunting, and related products in Castile and Leon, Catalonia, Madrid, and the Basque country, and Construction in Andalusia and Madrid.

A case study: Specific regional distribution of GWF associated with Madrid

From the results above, the role of Madrid and, to a lesser extent, Catalonia, as a final destination of water pollution flows in Spain is clear. As a case study, we focus on this region to analyse the specific distribution of its GWF. Map 4 summarizes the results.

(Insert Map 4)

The GWF from production exported to satisfy the final demand of Madrid shows two key affected regions; that of Madrid itself, and Castile-Leon. We can then identify a group of important supplier regions: Castile-La Mancha, Andalusia, Aragon, and Galicia - all regions that are agrarian producers, the kind of production that the region of Madrid demands above all others.

4.3. Scenario analysis: Macroeconomic changes and local effects

An example of how economic policy at the regional or national level can affect the local economy, highlighting the importance of combining IO models and GIS tools, can be seen in a scenario of imports substitution (for the Spanish regions), for example of agriculture and meat production.

We propose a scenario of a 20% substitution of foreign imports (in the Spanish regions) for meat production[7], finding its uneven effects and distribution across regions, e.g. for the Ebro river. The changes in the domestic production of agriculture and meat due to the cut in imports would vary in every Spanish region, depending on the inter-regional balance. Looking at the baseline result in Table 1 under this scenario, we get the quantity and percentage changes observed in Table 3. In particular, Table 3 shows changes in the GWF from production and consumption (hm^3) associated with the foreign import substitution (hence with domestic production) scenario by region.

(Insert Table 3)

Such a scenario would imply that Spain as a whole would increase its net GVW exports by 394 hm^3, with specific hotspots as those observed in regions such as the "Castiles", the Canary Islands, and Aragon, which would increase their exports to the large regional consumers, such as Catalonia and Madrid. In this scenario, the EU and RW reduce their GWF from production and GVW exports to the Spanish regions. On the other hand, the

[7] This scenario is in line with recent studies, and notions of food security and sovereignty, and follows the trend of reducing imports while trying to increase exports, as a way to maintain or increase trade and improve the trade balance. We are only interested here in studying the changes in GWF, which is why we do not analyse the economic equilibrium underlying these changes.

Spanish regions increase their GWF from production, mainly led by the need to satisfy their own final demands. The direction of the change in VW exports is variable among regions and, looking at the last row of Table 3, we see that the WF from consumption in a few regions would decrease. One advantage of the tools we have used in this work is the ability to examine expected local changes in goods and services production, and hence in the GWF from production. We observe how regions such as Navarre and Murcia, which have high coefficients of imports (only 30% of meat production is domestic), they would notably increase their GWF from production with the import substitution of meat, because they would increase the domestic production In the case of "the Castiles", even when they have low coefficients of imports (domestic production of livestock and meat production above 70%) they increase their GWF from production by increasing their export of both livestock and meat intermediates (and hence GVW). For Castile-La Mancha, there is also an important domestic component, given that their self-sufficiency is not as great as in Castile and Leon. Other highly self-sufficient regions, which would not significantly increase their GWF from production under this scenario, are the Basque Country, Catalonia, and Galicia. Regions such as Andalusia, Asturias, Extremadura, and La Rioja also have significant self-sufficiency in meat production and do not increase their GWF from production as much. In the case of Madrid, most of the GWF from a production increase would be generated elsewhere (essentially in the rest of the Spanish regions, such as the "Castiles", but also in La Rioja and Navarre, and, interestingly, in Aragon, Galicia, and Extremadura, with important primary and feed sectors).

If we assume that imports from other Spanish regions, and imports from abroad, decrease by 20%, with this being substituted for by domestic production, we would see those shown in Table S3, with more important changes, especially in the inter-regional VW. Even when the simulated scenario represents a change of less than 1% in the GWF from production in Spain as a whole, for individual ARs the changes range from -9% to 7%. In particular, the internal GWF from production could increase by up to 30%, as in the case of Navarre, while there is, in most cases, a decrease in GVW exports of, for example, up to 60% in flows from Aragon to the Balearic Islands. Apart from the expected decrease in GWF from production and GVW exports to the Spanish regions from the EU and RW, significant reductions in GVW exports appear in Aragon, Navarre, and Castile and Leon, with a joint reduction above 1,600 hm^3 led by the change in this last region. Given the initial very high self-sufficiency of Castile and Leon, the scenario implies relatively low substitution, while the meat trade and GVW exports from this region to the other Spanish regions are strongly reduced. In relation to Madrid, the substitution generates higher GWF from production in La Rioja, Navarre, Galicia, and Extremadura. These regions, under the import substitution scenario, are less affected than Catalonia in the loss of export revenue from meat exports to Madrid (or are relatively more affected in terms of GWF from production).

Making use of our interface of the inter-regional IO model, with localized business information, in Map 5 we examine the localized changes in the Ebro River basin. The colours of the spheres on the map indicate the magnitude of the change in grey water under the import substitution scenario, while the size of the spheres shows the relative significance of the location. In this case, we observe how the livestock areas in the north, and notably particular hotspots in the east, around the Noguera-Ribagorzana and Segre rivers in Lleida and Huesca (see also (Bayo et al., 2012), and at the estuary of the Ebro, would show the most significant GWF changes.

(Insert Map 5)

5 Discussion and conclusions

The motivation of our study is based on data, reports, and insights into concerns about water quality and its effects in Spain. We also attempted to fill the gap between estimates and intuitions on the GWF from agriculture and industrial activities, and the GVW flows involved among regions, and with the rest of the world. This could lead to a more comprehensive understanding of the roles of agents and their responsibilities and the capacity to establish good quality standards in specific areas, rivers, and lakes in Spain.

A key point has been the combination of IO and GIS models. To the best of our knowledge, this paper is also one of the first attempts to combine MRIO with GIS analysis. First, the MRIO model, constructed for the 17 Spanish regions, plus the EU and the RW, allows us to estimate the regional GWF and GVW trade. We have seen the importance of IO studies in analysing macroeconomic structures of regions and the environmental impacts associated with domestic final demand and trade, allowing us to conclude that, in order to avoid or minimize such impacts on water resources, we must consider technological options, industrial demands, trade patterns, and the lifestyles of citizens of the major trading partners. Our IO model works at the meso-and macro-economic level, including aspects such as value added and final demand. Major policy changes regarding subsidies, specializations, and trade usually take place at the regional or national level, but our contribution - combining an economic model with GIS – lies in the fact that the model accounts for sensitive local areas and examines the macro- or meso-economic scenarios reflected in changes in consumption patterns and regional exports. The data on rivers and water bodies such as lakes, and other related information such as run-off, water desalination, transfers, and vulnerable areas, complement and interlink with the spatial distribution of the economic activities identified by input-output sectoral classifications.

On the methodological choices, in our opinion, there can be debate as to whether only the limiting pollutant (for example, for agrarian production, nitrogen or phosphorus, and for industrial production, choosing among several pollutants) needs to be considered in the estimation of the GWF from production. Certain crucial choices, such as the one here of not only considering/assuming a "limiting factor" as a starting point, or the selection of data, and the pollutants leaching as non-point source pollution, may alter the computations. Here, rather than using the application of nitrogen and assuming a percentage of that application leaches as non-point source pollution, we followed some of the literature on computation directly from pollutant balances providing the surplus (application minus exits) of pollutants, which results in higher levels of leaching than the application of the usual 10% assumption of the application rate. We also estimated the industrial GWF from production, basing our methodology on the best available data on several pollutants. For all these reasons, our estimates of GWF from production may be considered an upper bound of the customary range of estimates in such studies.

Acknowledging these methodological choices, the limitations on pollutant data and their assessments, the results, in any case, may not depart so much from related intuitions in other studies, such as the strong claim (Greenpeace, 2005) that only 11% of the water in Spanish rivers and 16% of the water in Spanish aquifers are of acceptable quality, according to the parameters set by the Water Framework Directive of the EU. Furthermore, rather than focusing on the methodological choices, our study attempts to show the link between meso- and macro-changes, through interregional and global chains of production into the local areas, where the pollution actually occurs, and where the GWF from production can be measured, assessed, and compared to the water availability.

In our results, we also see that many of the Spanish regions are, as is often the case when studying blue and green VW, GVW importers. But this effect for most Spanish regions is not so clear-cut as in the case of green VW imports. This is mainly due to their important industrial production, with significant effect on the GWF from production, which end up being incorporated in GVW exports. Nevertheless, in certain cases (such as in the "Castiles" and Murcia) the main source of GWF from production is agrarian, due to agricultural concentration.

Some other specific results have been obtained in our analysis. First, the roles of Madrid and Catalonia as final consumers, having high volumes of GWF from consumption, originated mostly as GWF from production elsewhere in the Spanish territory. Second, the relatively limited share that the agriculture and food sectors have in GWF analysis (against its absolute dominance in green WF analysis), implies a need to broaden the focus to the industrial and services sectors for a more complete assessment of water pressures in the territories. Third, the specific behavior of some regions, such as Andalusia, with significant local GWF from production, is mainly due to production for export. Finally, we have computed and represented specific geographical representations of the GWF changes associated with a hypothetical scenario of a change in regional economic conditions. The policy implications for sustainability can be derived when studying the effects of an import substitution by the meat industry, in areas such as the Ebro River basin, leading to localized changes in a few hotspots, particularly in the North West and in the Eastern areas of the catchment.

From the point of view of the preservation of water resources, we can draw certain conclusions on water policy. We have identified how the current structure of production and trade significantly drive GWF from production generated in other regions (and countries). Consequently, the benefits of maintaining or increasing current levels of production in the regions can be assessed, to see if they generate sufficient economic resources to establish water purification systems, to recover water bodies to their original conditions, and in general to overcome the potential costs. We also see promising avenues for complementary studies (Aviso et al., 2011; Sánchez-Chóliz and Duarte, 2005) to evaluate WFs and VW trade in relation to water availability, optimizing supply and trade chains under water-availability or WF constraints, or vice-versa, minimizing WFs or water pollution while satisfying current demands. Policy-makers should focus on ways to promote the production of pollution-intensive goods in areas of greater water availability and dilution capacity, and on the establishment of requirements for cleaner production, broader environmental reserves, and similar potential water management options.

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Tables

Table 1: Summary of total grey water footprints (hm^3) of production and consumption by Spanish AR (region).

	Grey water footprint of Production				Grey water footprint of Consumption				Grey virtual water flows (positive means net export, negative, net import)			Percentage of grey virtual water (GVW) export (positive values) and import (negative values) compared to the other (blue and green) WF of production		
Regiones	Total	To own region (Internal WF of regional consumption)	To RS*	To EU+RW	Total	From own region (Internal WF of regional consumption)	From RS* (EWF**)	From EU+RW (EWF**)	Total Net Export	Net Export to RS*	Net Export to EU+RW	% GVW Export with respect to green WF of production	% GVW Export with respect to blue WF of production	% GVW Export with respect to the blue and green WF of production
Andalusia	**11,527**	5,266	2,795	3,465	**9,771**	5,266	2,558	1,946	**1,756**	237	1,519	58%	36%	**54%**
Aragon	**4,951**	1,261	2,581	1,109	**2,730**	1,261	815	654	**2,221**	1,766	455	48%	64%	**53%**
Castile-La Mancha	**6,558**	1,307	4,008	1,242	**2,573**	1,307	743	523	**3,985**	3,265	719	71%	59%	**69%**
Asturias	**1,793**	1,100	373	320	**1,858**	1,100	473	285	**-65**	-100	35	-64%	-16%	**-49%**
Balearic Islands	**1,366**	955	240	171	**2,142**	955	757	429	**-776**	-517	-259	-94%	-78%	**-89%**
Canary Islands	**3,046**	2,714	202	130	**4,700**	2,714	921	1,065	**-1,655**	-719	-935	-836%	-132%	**-408%**
Cantabria	**1,209**	653	302	254	**1,362**	653	522	187	**-153**	-220	67	-170%	6%	**-79%**
Castile and Leon	**13,685**	3,842	7,919	1,923	**5,100**	3,842	708	550	**8,585**	7,211	1,374	65%	53%	**63%**
Catalonia	**8,990**	4,353	2,188	2,448	**13,245**	4,353	4,355	4,536	**-4,255**	-2,167	-2,088	-222%	-58%	**-159%**
Galicia	**3,862**	1,641	1,436	785	**3,935**	1,641	1,028	1,266	**-72**	408	-480	-15%	-166%	**-29%**
La Rioja	**632**	175	325	131	**637**	175	215	247	**-5**	110	-115	10%	-24%	**5%**
Madrid	**5,801**	3,211	1,515	1,076	**13,453**	3,211	6,165	4,077	**-7,652**	-4,650	-3,001	-2,536%	-364%	**-1,232%**
Navarre	**2,488**	683	1,185	621	**1,710**	683	704	324	**778**	481	297	-4%	38%	**11%**
Basque Country	**2,435**	1,275	399	760	**5,657**	1,275	2,670	1,711	**-3,222**	-2,271	-951	-965%	-170%	**-563%**
Extremadura	**2,746**	743	762	1,241	**2,502**	743	1,264	495	**244**	-503	747	34%	57%	**40%**
Murcia C&M	**1,610**	467	284	859	**3,678**	467	2,380	831	**-2,068**	-2,095	27	-911%	-32%	**-282%**
Valencian C.	**7,902**	2,843	2,231	2,829	**7,504**	2,843	2,467	2,194	**399**	-236	635	-446%	1%	**-170%**
Total Spain	**80,601**	**32,491**	**28,746**	**19,365**	**82,557**	**32,491**	**28,746**	**21,321**	**-1,956**	**0**	**-1,956**	**-179%**	**-64%**	**-142%**

* RS: Rest of Spain. ** EWF: External water footprint of regional consumption

Source: Own elaboration.

Table 2: Bilateral (double-entry) matrix of the grey virtual water export flows (hm^3) among Spanish ARs (regions). The main diagonal shows the Internal water footprint of regional consumption and the elements outside the main diagonal the grey virtual water flows .

	Andalusia	Aragon	Castile-La Mancha	Asturias	Balearic Islands	Canary Islands	Cantabria	Castile and León	Catalonia	Galicia	La Rioja	Madrid	Navarre	Basque Country	Extremadura	Murcia, Ceuta & M.	Valencian C.	European Union	Rest of the World	**Net Grey VW Export**
Andalusia	5,266	53	68	25	145	98	14	46	464	75	4	487	39	115	283	511	367	2,284	1,181	1,756
Aragon	128	1,261	69	12	30	47	19	42	1,086	38	34	452	131	112	23	119	240	642	467	2,221
Castile-La Mancha	524	80	1,307	15	17	48	44	65	448	71	6	1,198	51	73	235	637	495	547	696	3,985
Asturias	35	9	12	1,100	10	7	34	43	39	51	2	51	5	25	6	14	30	160	161	-65
Balearic Islands	19	9	3	2	955	28	1	3	52	7	1	67	1	3	2	19	23	88	82	-776
Canary Islands	73	2	2	2	11	2,714	3	3	20	6	0	24	2	37	3	4	11	54	75	-1,655
Cantabria	26	6	5	12	7	6	653	31	47	14	2	49	6	51	4	9	27	133	121	-153
Castile and Leon	423	158	225	143	33	127	211	3,842	950	422	64	2,172	231	1,451	465	277	568	1,100	824	8,585
Catalonia	259	148	61	51	213	139	41	77	4,353	121	18	392	72	127	46	139	284	1,324	1,124	-4,255
Galicia	150	51	27	118	24	58	36	98	176	1,641	4	307	43	140	35	65	104	456	329	-72
La Rioja	11	22	5	6	2	5	4	28	39	11	175	41	34	99	3	5	12	76	55	-5
Madrid	253	45	111	37	49	178	35	101	197	81	16	3,211	22	71	75	108	135	548	528	-7,652
Navarre	70	77	15	13	41	25	23	34	283	20	46	162	683	248	28	49	52	360	261	778
Basque Country	34	15	8	13	13	11	25	38	67	23	8	67	26	1,275	5	16	27	398	363	-3,222
Extremadura	199	29	23	5	7	17	9	38	73	13	2	248	5	25	743	27	40	866	375	244
Murcia C&M	78	1	6	1	40	6	0	2	42	2	0	41	4	1	9	467	51	251	607	-2,068
Valencian C.	276	111	101	17	116	124	23	59	373	73	7	408	30	90	41	381	2,843	1,341	1,488	399
European Union	681	302	197	116	198	386	54	249	1,754	499	73	1,538	154	627	134	277	739	503,299	249,828	-77,996
Rest of the World	1,265	352	326	169	231	679	133	301	2,782	766	174	2,539	170	1,085	361	555	1,455	325,173	2,524,090	79,952
WF of consumption	**9,771**	**2,730**	**2,573**	**1,858**	**2,142**	**4,700**	**1,362**	**5,100**	**13,245**	**3,935**	**637**	**13,453**	**1,710**	**5,657**	**2,502**	**3,678**	**7,504**	839,101	2,782,654	0
WF of consumption from Spanish regions	**7,824**	**2,077**	**2,048**	**1,572**	**1,713**	**3,638**	**1,175**	**4,550**	**8,709**	**2,669**	**389**	**9,377**	**1,385**	**3,943**	**2,006**	**2,847**	**5,309**	**10,628**	**8,737**	**-1,956**

Source: Own elaboration.

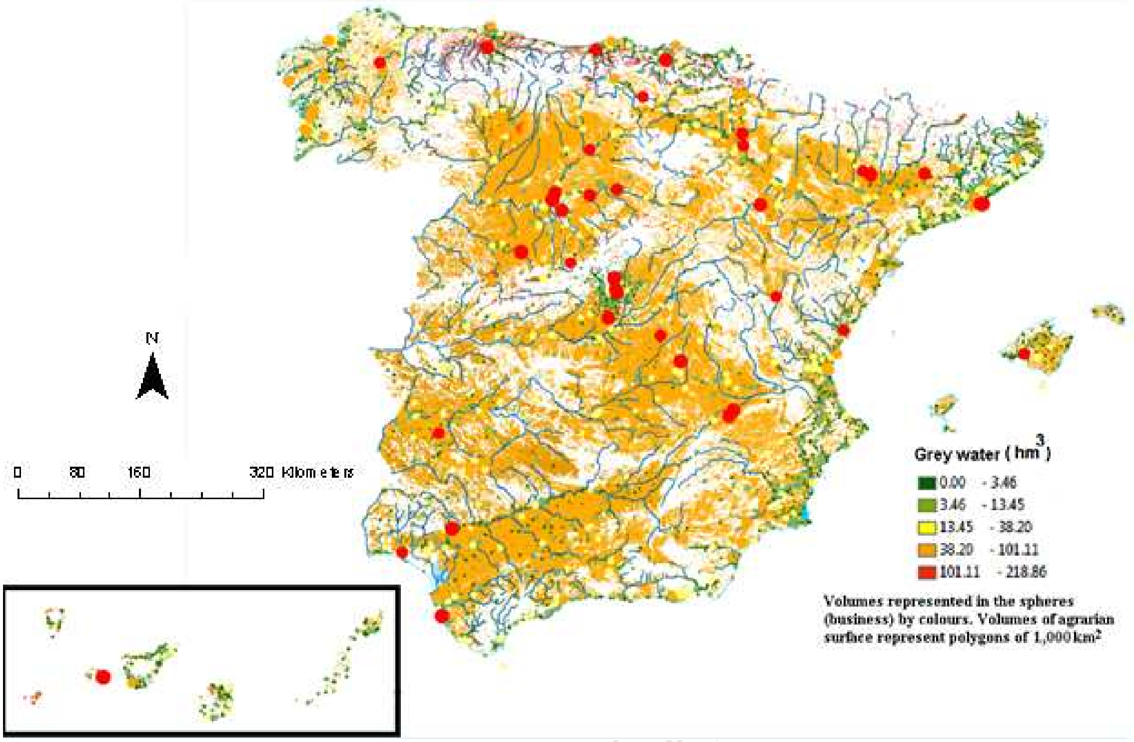
Table 3. Changes in the bilateral (double-entry) grey virtual water flows with the 20% foreign import substitution of meat

	Andalusia	Aragon	Castile-La Mancha	Asturias	Balearic Islands	Canary Islands	Cantabria	Castile and León	Catalonia	Galicia	La Rioja	Madrid	Navarre	Basque Country	Extremadura	Murcia, Ceuta & M.	Valencian C.	European Union	Rest of the World	Total grey water footprint of production (%)	Total direct grey water cons. (hm^3)	Net Grey Water Export
Andalusia	0.2%	0.0%	0.6%	0.1%	0.7%	0.3%	0.3%	0.0%	0.9%	-0.1%	0.5%	1.1%	0.1%	-0.2%	0.1%	1.5%	0.2%	-0.2%	-0.2%	**0.2%**	**20**	**25**
Aragon	0.5%	0.5%	0.7%	1.0%	0.7%	1.5%	0.6%	0.4%	2.0%	0.5%	0.5%	1.9%	0.1%	0.2%	0.9%	1.0%	0.8%	0.2%	0.0%	**0.9%**	**44**	**40**
Castile-La Mancha	0.4%	0.6%	2.8%	0.8%	0.6%	1.1%	1.2%	0.4%	1.7%	0.5%	0.9%	2.1%	0.4%	0.6%	0.6%	1.5%	0.7%	0.4%	0.0%	**1.3%**	**93**	**77**
Asturias	0.0%	0.1%	0.1%	0.1%	0.0%	0.3%	0.2%	0.0%	0.2%	0.0%	0.6%	0.1%	0.1%	0.0%	0.1%	1.6%	0.2%	0.0%	0.0%	**0.1%**	**2**	**2**
Balearic Islands	0.3%	0.1%	0.6%	0.3%	0.4%	0.6%	0.5%	0.2%	0.3%	0.3%	0.6%	0.4%	0.4%	0.2%	0.3%	1.7%	0.5%	0.2%	0.1%	**0.4%**	**5**	**9**
Canary Islands	0.1%	0.2%	0.4%	0.1%	0.1%	0.6%	0.2%	0.1%	0.5%	0.0%	0.5%	0.9%	0.1%	0.1%	0.1%	1.0%	0.4%	0.0%	0.0%	**0.6%**	**17**	**64**
Cantabria	0.1%	0.3%	0.4%	0.1%	0.1%	0.5%	0.6%	0.2%	0.8%	0.1%	0.7%	0.3%	0.2%	0.0%	0.2%	1.6%	0.4%	0.0%	0.0%	**0.4%**	**5**	**10**
Castile and Leon	0.1%	0.3%	0.8%	0.1%	0.3%	0.6%	0.0%	0.2%	0.9%	-0.1%	1.1%	1.6%	0.0%	-0.2%	0.2%	-0.2%	0.5%	0.1%	-0.5%	**0.4%**	**51**	**49**
Catalonia	0.3%	0.4%	0.5%	0.3%	0.2%	0.8%	0.5%	0.3%	0.7%	0.2%	1.0%	0.7%	0.5%	0.4%	0.5%	1.9%	0.7%	0.1%	0.1%	**0.5%**	**45**	**33**
Galicia	0.1%	0.4%	0.9%	0.6%	0.0%	0.4%	0.0%	0.1%	1.2%	0.1%	1.1%	2.0%	0.0%	-0.2%	0.0%	0.2%	0.3%	-0.1%	-0.3%	**0.3%**	**11**	**14**
La Rioja	0.2%	0.7%	1.2%	0.4%	0.3%	0.8%	0.4%	0.0%	1.6%	-0.1%	0.1%	2.1%	-0.1%	-0.3%	0.3%	-0.6%	0.6%	0.0%	-0.3%	**0.3%**	**2**	**7**
Madrid	0.1%	0.1%	0.6%	0.2%	0.1%	0.6%	0.3%	0.1%	0.3%	0.1%	0.5%	0.3%	0.2%	0.1%	0.3%	0.4%	0.3%	0.1%	-0.2%	**0.2%**	**13**	**-28**
Navarre	0.8%	0.9%	1.1%	1.1%	0.7%	1.0%	1.2%	0.6%	2.1%	0.5%	0.7%	2.4%	1.4%	0.2%	0.8%	1.5%	1.4%	0.3%	0.2%	**1.1%**	**27**	**21**
Basque Country	0.0%	0.2%	0.2%	0.1%	0.0%	0.5%	0.3%	0.1%	0.3%	0.1%	0.8%	0.2%	0.1%	0.5%	0.1%	1.6%	0.2%	0.0%	0.0%	**0.3%**	**7**	**30**
Extremadura	0.2%	0.2%	0.9%	0.5%	0.0%	0.7%	0.2%	0.2%	1.6%	0.0%	0.6%	2.0%	0.3%	0.0%	0.4%	-0.9%	0.4%	-0.2%	-0.3%	**0.2%**	**7**	**9**
Murcia C&M	1.0%	0.8%	0.9%	0.9%	1.0%	0.8%	-0.2%	0.9%	1.0%	0.9%	-0.6%	1.1%	1.0%	0.1%	1.0%	2.8%	0.0%	0.0%	0.0%	**0.8%**	**16**	**-6**
Valencian C.	0.3%	0.6%	1.0%	0.3%	0.7%	0.5%	0.3%	0.1%	1.8%	0.1%	0.5%	1.1%	0.4%	0.1%	0.4%	0.1%	1.1%	0.0%	0.1%	**0.6%**	**49**	**37**
European Union	-1.3%	-1.0%	-9.7%	-1.7%	-3.5%	-3.6%	-3.2%	-1.4%	-2.6%	-0.7%	-1.7%	-2.9%	-1.1%	-2.8%	-4.3%	-2.2%	-2.1%	0.00%	0.00	**-0.1%**	**-210**	**-197**
Rest of the World	-1.0%	-0.7%	-2.3%	-0.8%	-1.7%	-8.1%	-6.8%	-1.3%	-1.1%	-0.3%	-3.6%	-0.9%	-2.0%	-0.8%	-0.9%	-1.4%	-1.2%	0.00%	0.00	**0.0%**	**-226**	**-197**
Destination (%)	**-0.1%**	**0.1%**	**0.6%**	**0.0%**	**-0.2%**	**-1.0%**	**-0.4%**	**0.0%**	**0.1%**	**-0.1%**	**-0.9%**	**0.3%**	**0.3%**	**-0.4%**	**-0.1%**	**0.7%**	**0.2%**	**0.0%**	**0.0%**	**0.0%**		
WF of consum. (hm^3)	**-5.6**	**4.0**	**15.2**	**-0.5**	**-3.9**	**-46.5**	**-5.5**	**2.2**	**12.3**	**-3.2**	**-5.6**	**40.5**	**5.3**	**-22.5**	**-2.3**	**21.9**	**12.0**	**-9**	**-33**		**-20**	**0**
Destination Spain (hm^3)	**15.9**	**9.5**	**41.9**	**2.8**	**7.0**	**22.6**	**5.2**	**9.7**	**89.3**	**2.7**	**2.0**	**107.8**	**10.5**	**4.3**	**6.7**	**35.9**	**44.9**	**1**	**-7**		**412**	**394**

Source: Own elaboration.

Maps

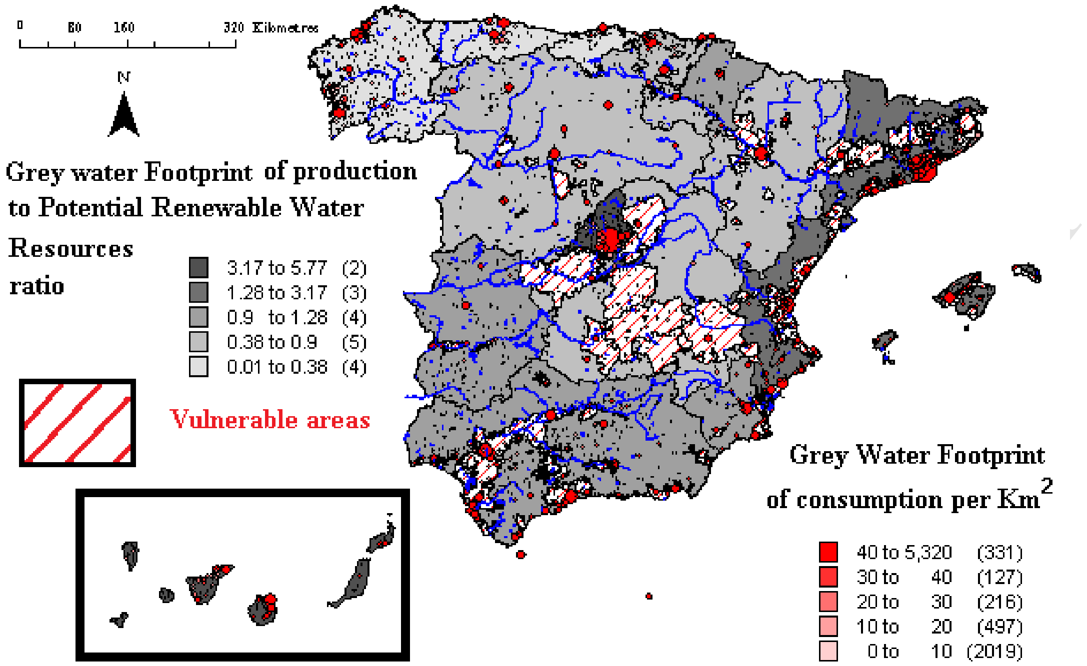
Map 1. Direct grey water associated to business and agrarian activities (size by grey water*).



The direct grey water by business is shown by the green (less grey water)-yellow-red (more) scale, bringing forward the hotspots by higher grey water. The size of the spheres represents also the size of the point source grey water footprint,of production, so the importance is stressed both by the colour and size).
Regions (CCAAs) are delimited in white, and rivers and reservoirs are shown in blue.

Source: Own elaboration, with databases on rivers, vulnerable and sensible areas.
http://servicios2.marm.es/sia/visualizacion/descargas/mapas.jsp

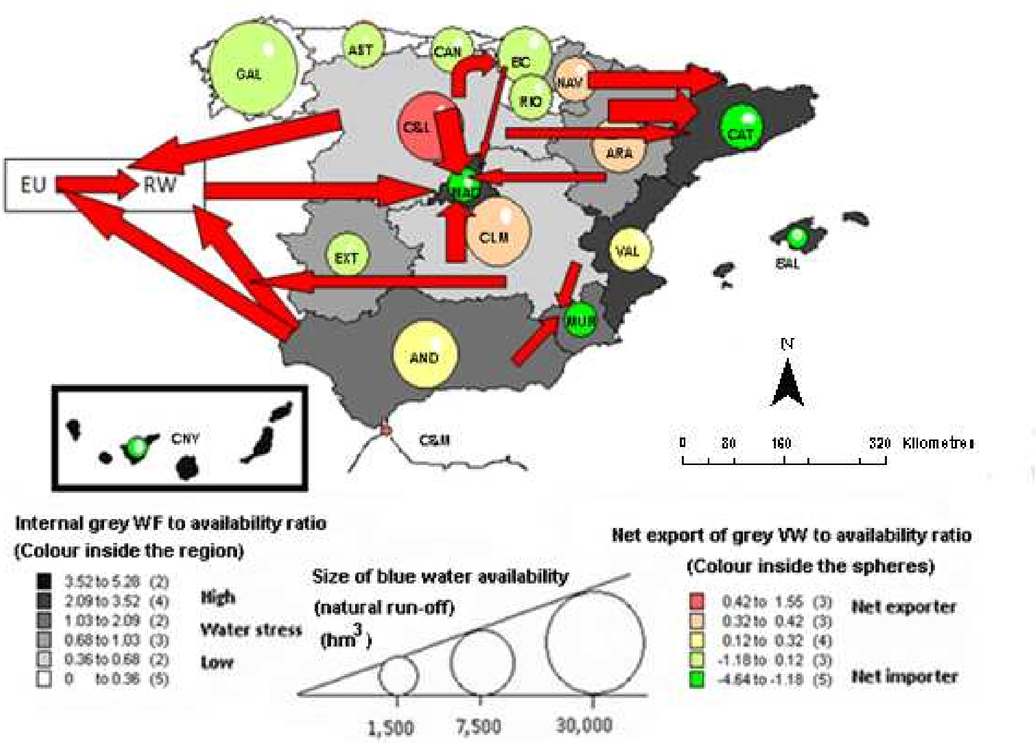
Map 2: Grey water footprint of production to potential renewable water resources (PRWR, by region) ratio and Grey water footprint of consumption per Km^2



Note: Grey Water Footprint per km2 is the grey water footprint of consumption of the region divided per area.
The size of the spheres represents the size of the Grey Water Footprint of consumption in each village, town or city.

Source: Own elaboration, using databases on rivers and vulnerable and sensible areas.
http://servicios2.marm.es/sia/visualizacion/descargas/mapas.jsp

Map 3: Internal grey WF and net export of GVW compared to natural water availability (run-off)

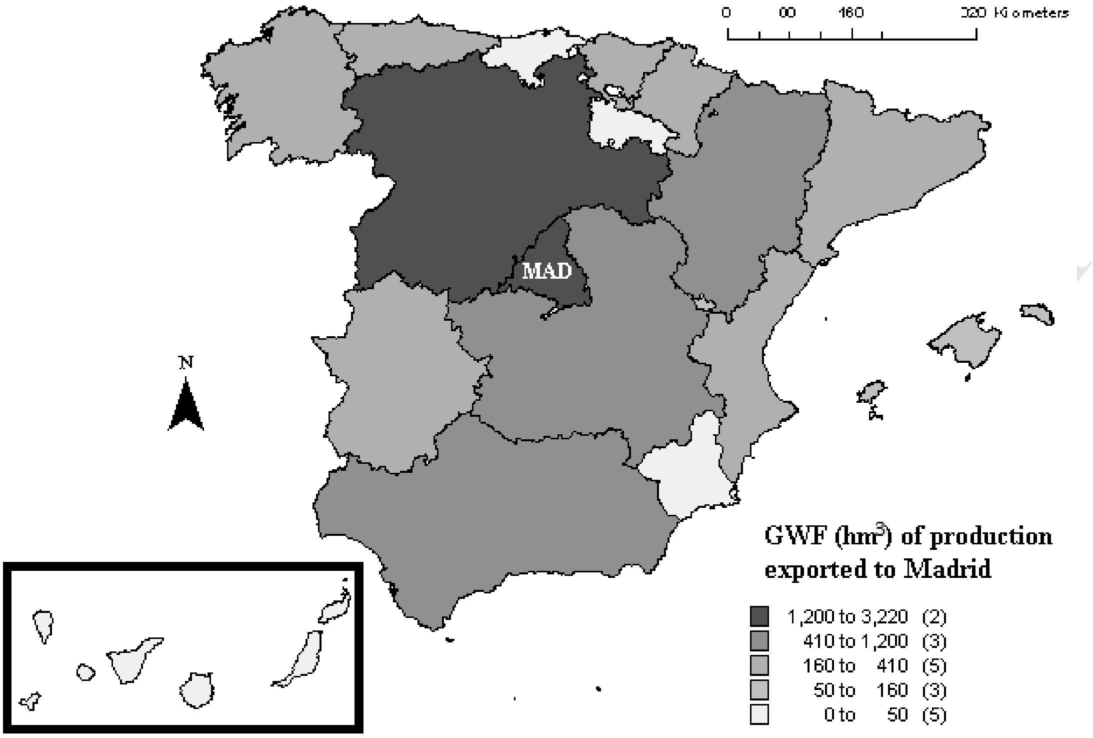


GAL. Galicia, AST. Asturias, CAN. Cantabria, BC. Basque Country, NAV. Navarre, RIO. La Rioja, ARA. Aragon, MAD. Madrid, C&L. Castile and Leon, CLM. Castile-La Mancha, EXT. Extremadura, CAT. Catalonia, VAL. Valencian C., BAL. Balearic islands (Baleares), AND. Andalusia, MUR. Murcia, C&M. Autonomous cities of Ceuta y Melilla, CNY. Canary islands (Canarias).

Note: We refer to high or low water stress with the colour in the regions, since water does not display grey water pollution, but the need to dilute contaminants. The arrows show represented some major net virtual grey water flows between regions (not shown all existing flows).
The color of the spheres relates to net export of GVW divided by the natural water availability (run-off).

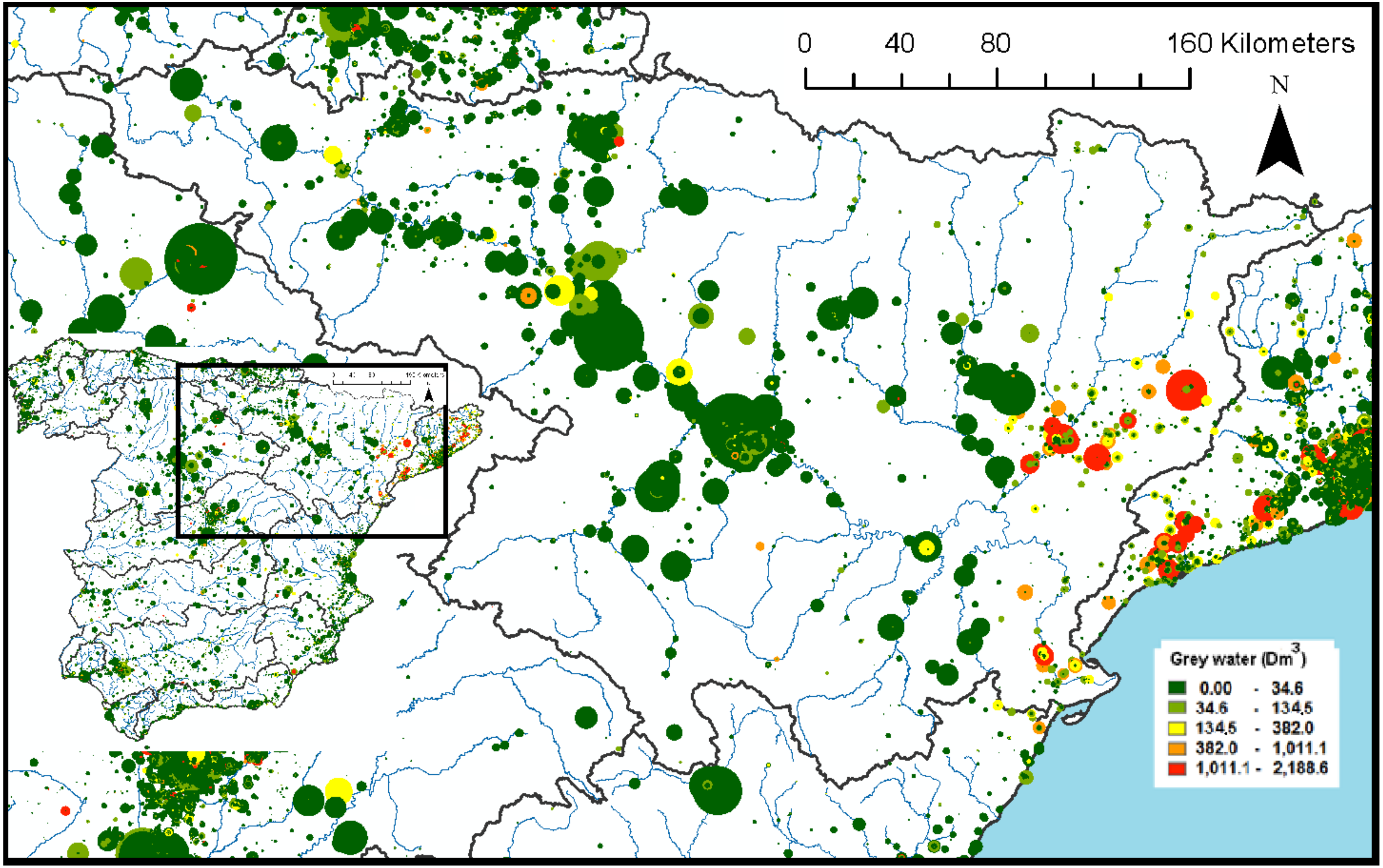
Source: Own elaboration.

Map 4: Origin of the GWF of production exported to Madrid for their final demand



Source: Own elaboration.

Map 5. Localized changes in origin and destination of grey water change with the foreign import substitution by each region of meat



The size of the spheres represents the size of the business (of a particular enterprise) in terms of number of workers.

Source: Model results.

Highlights

- We model the grey virtual water interregional flows and footprints in Spain
- The meso-economic input-output model is combined with GIS localized information
- Vulnerable areas in the Castiles, Aragon and Andalusia are affected by production mostly destined to export
- 21 of the 83 km^3 of grey WF from consumption in the Spanish regions come from other countries
- We localize direct and indirect impacts of macro-meso scale changes as the level of imports changes.

Supplementary Information

Methodology and Data Sources

This section extends on the section "3 Methodology and Data Sources" of the Manuscript, providing more detail to the type of methods and computations performed.

Multi-regional Input-Output (MRIO) model extended for Water Footprint estimates

The model used is based on the interregional and multiregional models of (Chenery, 1953; Isard, 1951; Miller and Blair, 2009; Moses, 1955), with the equilibrium equation (1) being:

$$\mathbf{X}^{\oplus} = \mathbf{A}^{\oplus}\mathbf{X}^{\oplus} + \mathbf{Y}^{\oplus} \Leftrightarrow \mathbf{X}^{\oplus} = \left(\mathbf{I} - \mathbf{A}^{\oplus}\right)^{-1}\mathbf{Y}^{\oplus} = \mathbf{L}^{\oplus}\mathbf{Y}^{\oplus} \quad (1)$$

Where $\mathbf{A}^{\oplus}$ is the multi-regional matrix of technical coefficients, $\mathbf{L}^{\oplus}$ its Leontief inverse, $\mathbf{X}^{\oplus}$ the output matrix and $\mathbf{Y}^{\oplus}$ the final demands matrix.

In $\mathbf{A}^{\oplus}$, each 40x40 matrix $\mathbf{A}_{rr}$ indicates the domestic technical coefficients in region *r*. The 40x40 off-diagonal matrices $\mathbf{A}_{rs}$ indicate the coefficients of region *s* of imported inputs from *r*. Each element a_{rs}^{ij} of the matrix $\mathbf{A}^{\oplus}$ expresses the quantity of output of sector *i* produced in *r* and consumed as input by sector *j* of region *s*, per unit of total output of sector *j* in *s*.

Matrix $\mathbf{Y}^{\oplus}$ is formed of 19 column vectors $\mathbf{y}_s$ with vector $\mathbf{y}_{ss}$ (40x1) representing the domestic final demand of *s*, and with the other $\mathbf{y}_{rs}$ being the final demands of goods from *r* to *s* not consumed as productive inputs, i.e., the flows of finished products from *r* to *s*.

Matrix $\mathbf{X}^{\oplus}$ is formed of 19 column vectors $\mathbf{x}_s$ each of which represents, according to (1), the production needed to obtain final demand $\mathbf{y}_s$. This production can be broken down into $\mathbf{x}_{ss}$ (a 40x1 vector), which is the production of *s* used to fulfil the final demand $\mathbf{y}_s$, and vectors $\mathbf{x}_{rs}$ which quantify the additional production needed from the other regions *r*.

We obtain the grey water flows and footprints, in a similar way to the green and blue VW flows and footprints in (Cazcarro et al., 2013). Diagonalizing each of these vectors to obtain $\mathbf{Y}^{\oplus^{+}}$, and making use of $\hat{\mathbf{w}}^{\oplus}$, the matrix of the diagonalized grey water footprint of production coefficients (grey water footprint of production per unit of economic output), we obtain $\mathbf{H}^{\oplus}$, which as each of the three elements in the following equation has dimension of 760x760.

$$\mathbf{H}^{\oplus} = \hat{\mathbf{w}}^{\oplus}\mathbf{L}^{\oplus}\mathbf{Y}^{\oplus^{+}} \quad (2)$$

Empirically, our first objective is to estimate $\mathbf{H}_{r,s}$ a double-entry matrix showing the grey virtual water flows from region *r* to region *s*, and to identify the different components presented above.

Each $\mathbf{H}_{r,s}$ (40x40) is then a matrix showing the grey virtual water flows from region *r* to region *s* (whose elements h_{rs}^{ij} represent, in input-output terminology, the direct and indirect embodied grey water to meet the demands of sector *j* in region *s* from sectors *i* of region *r*).

Then, with $\mathbf{e}$ being a column vector of ones, $\mathbf{e}'\mathbf{H}_{s,s}\mathbf{e}$ is the grey water footprint generated in region *s* to support its own final demand. In other words, this is the domestic component of the grey WF of region *s*, i.e., the internal water footprint of regional consumption of region *s*. Similarly, $\sum_{\substack{r \\ r\neq s}} \mathbf{e}'\mathbf{H}_{r,s}\mathbf{e}$ is the total grey virtual water import of region *s* (from all other regions), and $\sum_{\substack{s \\ s\neq r}} \mathbf{e}'\mathbf{H}_{r,s}\mathbf{e}$ the total grey virtual water export of region *r* (to all other regions). Hence, $\sum_{\substack{s \\ s\neq r}} \mathbf{e}'\mathbf{H}_{r,s}\mathbf{e} - \sum_{\substack{r \\ r\neq s}} \mathbf{e}'\mathbf{H}_{r,s}\mathbf{e}$ is the net export of grey virtual water. Moreover, $\sum_{r} \mathbf{e}'\mathbf{H}_{r,s}\mathbf{e} = \mathbf{e}'\mathbf{H}_{s,s}\mathbf{e} + \sum_{\substack{r \\ r\neq s}} \mathbf{e}'\mathbf{H}_{r,s}\mathbf{e}$ is the WF of consumption of region *s*.

Similarly, the vectors $\mathbf{h}'_s = \sum_{r} \mathbf{e}'\mathbf{H}_{r,s}$ of the grey water footprint of consumption in region *s* can be combined with different territorial socio-economic matrices $\mathbf{G}_{s,c}$, $\mathbf{G}_{s,m}$, $\mathbf{P}_{s,c}$, $\mathbf{P}_{s,m}$ representing coefficients of expenditure and population share by village/city c and municipality m, to spread/localize the embodied impacts, e.g. by $\mathbf{h}'_c = \mathbf{h}'_s\mathbf{G}_{s,c}$. In this work, given that the production side already shows enough complexity and requires careful detail on methods and results, we focus on the detailed location of grey water footprint of production, while only providing the results of grey water footprint of consumption at the regional (Autonomous Region) level.

Detail on Grey water footprint of production estimates at the regional level

The estimates of the grey water footprint of production is obtained and assigned at the business level, but the process of estimation departs from macro totals both at the regional level, combined with the information at catchment and business levels. To have an estimate of $\hat{\mathbf{w}}^{\oplus}$, the (direct) intensities of the grey water footprint of production by region, we try to follow the main insights and methodology of (Hoekstra et al., 2009, 2011; Mekonnen and Hoekstra, 2010b, 2011), with similar approaches adapted to our data availability and scope of analysis, since we cannot get all the ideal information necessary to estimate the grey water footprint of production in the ideal way explained in those works.

Where w_{agr_i} is the agricultural grey water footprint of production. In (Hoekstra et al., 2009, 2011; Mekonnen and Hoekstra, 2010b), what we call here, L_δ, the seeping of the limiting pollutant, is obtained by multiplying the fraction of limiting pollutant (nitrogen or phosphorus) that seeps (δ, %), at the rate of application per hectare per crop i (AR_i, kg/ha per year). In this work, given that for the Spanish regions we do not only know AR_i, but also the already the excess of nitrogen of the Spanish agriculture by province (and region) and category (crop type, animal residual, etc.) from the Nitrogen balances accounting (MAPA, 2011), we directly use that excess of N as L_δ in kg/ha per year[1,2] per province, using either nitrogen or phospurus (the higher grey water footprint of the two in each province following equation 3) as limiting pollutant in each province. In other words, instead of using the application rate per hectare per crop i (AR_i, kg/ha per year) from a general data source as (FAO, 2009; Heffer, 2009; IFA, 2009) -which logically were used to be consistent across countries and better from a recognized database- we use the data on excess of nitrogen of the Spanish agriculture by province (and region) and category (crop type, animal residual, etc.)(MAPA, 2011). The question of the percentage of nitrogen applied leaching δ is then not considered here, although as an intuition, according to this data source for Spain as a whole (there is high temporal and spatial variability though) the excess of N results in the years 2005-2008 between 8% to 23% of the N applied, and implicitly the lixiviation rates are assumed above the usual assumption of δ=10%.

All in all, since we know the levels of excess of nitrogen and phosphorus, the limiting pollutant is decided by region, since we get by region the maximum (volume of regional grey water footprint of production) of the two. Nitrogen is usually taken as the limiting pollutant, also taking into account that it is much more abundant element in nature than phosphorus, more often used as a fertilizer and found in high concentrations in agricultural runoff.

Thus the physical coefficient for grey water ($\overline{w}_{agr}$, m^3/ton) is calculated, by dividing the above by the difference between the maximum acceptable concentration of limiting pollutant ($c_{\max}$, 50 mg/l = 50^{-3} kg/m^3 for nitrogen[3] and 1 mg/l for phosphorus, according to (BOE, 1994, 2006)[4] and other similar legislations) and its natural concentration in the receiving water body (c_{nat}, kg/ m^3 , which we assume[5], as in (Mekonnen and Hoekstra, 2010a; Mekonnen and Hoekstra, 2011) and many other works, to be 0) and then divided by the crop yield i (Y_i, ton/ha per year).

$$\overline{w}^{grey}_{agr\ \ i} = \left(\frac{L}{c_{\max} - c_{nat}} \right) \frac{1}{Y_i} \tag{3}$$

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[1] This excess of N as in kg/ha per year is obtained in the cited publication as the difference between entries and exits of N, for each province and group of crop and grazing. The entries are composed by mineral fertilization, organic fertilization, droppings (grazing), biological fixation, seeds and atmospheric deposition. The exits comprise extractions (removed), volatilization (crops and grazing) and gases (crops and grazing).

[2] Following this same data source, alternative methods for the computation of the grey water footprint in one of the main catchments in Spain have been used in García, Á.d.M., 2013. La huella hídrica como indicador de presiones: aplicación a la cuenca del Duero y al sector porcino, Departamento de Química Analítica, Química Física e Ingeniería Química. Universidad de Alcalá, Alcalá de Henares. In particular, instead of assuming that 10% of the nitrogen applied as fertilizer is lost through leaching, a regression model was proposed following De Willegen, P., 2000. An analysis of the calculation of leaching and denitrification losses as practised in the NITMON approach, Report 18. Plant Research International, Wageningen.

[3] The limit established in the EU and Spain of 50 mg/l is of NO_3, so given the molecular masses, 50*14/62 = 11.3 mg/l of N (very similar to the limit in the USA of 10mg/l of N).

[4] After studying the potentially most dangerous pollutants in agriculture, we took, from the cited legislation on the matter which defines the concentration for surface water that is likely usable for human consumption, as limiting parameters (those which will allow the maximum permissible concentration), nitrogen (at 50 mg/liter), and marginally considered, phosphorus (at 0.7-1.7 mg /liter).

[5] In the assessment made in 2004 by EEA, it was recognized that nutrients occur naturally but it is difficult to determine precise background concentrations for different types of river. Generally background concentrations for phosphate were in the EU approximately 10 µg/l as P and for nitrate are between 0.4 to 4 mg/l as NO_3.

To estimate the industrial (and services, which are marginal) grey water footprint in physical units $\overline{w}_{ind\,i}$ (in m^3 as water needed to dilute the pollutants to acceptable concentration levels), we make use of the water satellite accounts and several studies on water quality by the Ministry of Environment, and the Legislation on the matter. After studying the potentially most dangerous pollutants and the availability of data, we account for nitrogen, phosphorus, chemical and biochemical oxygen demand and metals.

In order to estimate the grey water footprint from point source (pollution), it is required, according to the WF manual (Hoekstra et al., 2009, 2011), not only the volume of water abstracted and volume of effluent returned, but also the actual concentration (c_{act}) at the point of abstraction and the concentration of the chemical in the effluent (c_{effl}).

For Spain, the closest information that we may obtain is, on the one hand, at the regional (Autonomous Communities) level, the concentration for 6 main pollutants (DBO, DQO, Suspended Solids, Nitrogen, Phosphorus, Metals) of the regional effluents (returned to the water bodies), both before treatment and after treatment (INE, 2011a). We use this information since we also obtain from (INE, 2011b), the volumes of effluent that are treated in treatment plants ($Effl_{treat}$) and those that are not ($Effl_{untreat}$). For those 6 main pollutants we also know the concentration of the effluents by economic sector for some basins and for the whole Spain (see also (MMA, 2011a)). In particular we may know and use the coefficients on the concentration (mg/l) of water before ($c^{untreat}$) and after treatment (c^{treat}), which relate to the water data and balances on abstraction and discharges to public sewers and other discharges (INE, 2011a, b, c). For those 6 main pollutants we also know the concentration of the effluents by economic sector in the whole Spain (see also (MMA, 2011a)).
Finally, the maximum allowed concentrations for the 6 main pollutants is obtained from (BOE, 1994, 2006). In particular, apart from the limits provided above on N and P, the maximum Chemical Oxygen Demand (COD) is set at 30 mg/l and the Biochemical Oxygen demand (BOD5) at 7mg/l. The formulae for the estimation of industrial (point source) grey water footprint, is obtained then at the regional level as:

$$\overline{w}^{treat}_{ind\quad i} = \left(\frac{c_{treat} Effl_{treat,\ i} - c_{abstr} Abstr_i}{c_{\max} - c_{nat}} \right) \tag{4}$$

$$\overline{w}^{untreat}_{ind\quad i} = \left(\frac{c_{untreat} Effl_{untreat,\ i} - c_{abstr} Abstr_i}{c_{\max} - c_{nat}} \right) \tag{5}$$

Where $Abstr_i$ is the water volume (in time, which as all the volumes considered here, is a year) of the abstraction of water by an industry i and c_{abstr} is the concentration of the actual concentration of the intake water (all the concentration coefficients, in mass/volume).
$\overline{w}^{treat}_{ind\quad i}$ is the industrial grey water footprint from treated water, $Effl_{treat,i}$ the volume (effluent) of treated water returned by type of industry i, and c_{treat} the concentration of that treated effluent when delivered back to the water bodies.
$\overline{w}^{untreat}_{ind\quad i}$ is the industrial grey water footprint from untreated water, $Effl_{untreat,i}$ the volume (effluent) of untreated water returned by type of industry i, and $c_{untreat}$ the concentration of that untreated effluent when delivered back to the water bodies.
The idea behind these formulae is also estimating the differential, the added concentration of the industrial processes in their wastewater generated, in order to obtain the grey water footprint. Instead of doing it business by business (something which we can only do for some

of them, and in any case only knowing the waste in tons of pollutants, not the concentration in the water bodies), we estimate it at the sectoral aggregate level by region and by year.

The information by businesses is used to locate spatially these estimations per sector and region. For some of them we have the total quantity (kg per year) of pollutants or emissions to water (PRTR-España, 2010). In order to obtain also the geographical location of these businesses, and identify them in the SABI database (SABI, 2013), we link this database with the European registry of this type of emissions on pollutants to water ((EEA, 2010), which identify them also by national ID) which provides this feature and some other ones such as production volumes or number of employees (for the year 2005). We also have this information on revenue and number of employees for all the business in the SABI database, and hence the apportioning/assignation of the grey water footprint by sector and region for those businesses for which we do not have information on emissions to water, we do it according to their share in the sectoral revenue. Since we did not know the abstractions and effluents by particular businesses, the grey water footprint of these businesses with info on emissions to water was estimated directly by the proportion of pollutant emitted with respect to the sector in the region. Truly probably some of these businesses have different proportions of effluent returned compared to the abstraction made, something which would alter their contribution in grey water footprint of production, so further refinements could be done to these estimates.

From $\overline{w}_{agr\ i}^{grey}$ and $\overline{w}_{ind\ i}^{vol} = \overline{w}_{ind\ \ i}^{treat} + \overline{w}_{ind\ \ \ i}^{untreat}$, we obtain $w_{agr\ i}$ and $w_{ind\ i}$, the coefficients of direct grey water (in monetary units, m^3/euro) by dividing the grey water of production volumes by the value of production x_i of the crop or sector i in euros. $w_{agr\ \ i}^{grey} = \overline{w}_{agr\ \ i}^{grey} \cdot \overline{x}_i / x_i$ and $w_{ind\ \ i}^{grey} = \overline{w}_{ind\ i}^{vol} / x_i$. Where $\overline{x}_i$ is the agricultural physical production in tons.

The coefficients obtained in this way based on the existing statistical information, are defined at the regional and sectoral levels, being valid for inclusion in the multiregional IO model.

Detail on Grey water footprint of production estimates at the business level

Finally, the next step is to link the grey water footprint of production, with the specific enterprises in the territory. The purpose of using GIS databases is to link the grey water footprint of production, with the specific enterprises in the territory. If we assume that the grey water footprint of production has a distribution across the territory based on the polluting levels and distribution of businesses and (sectoral) specialization, the vectors $\mathbf{H}_{r,s}\mathbf{e}$ can be combined with a correspondence matrix $\mathbf{C}_m$ that distributes the grey water footprint of production from each sector i in region s to the various municipalities m, according to, if possible, the participation of each company of the sector in the grey water footprint of production, and otherwise on income (turnover). The information by businesses (for which we gather the information on activity or sector and link it to the 40 MRIO sector classifications) for the year 2005 from (SABI, 2013)[6] is used to locate spatially these estimations per sector and region. For some of these businesses we have the total quantity (kg per year) of emissions (by pollutant) to water (PRTR-España, 2010)[7] and for all the

[6] The information gathered comprises about 145,000 enterprises (those with 10 or more employees), comprising 7.5 million workers and 1,598,009 million euros of revenues.
[7] PRTR-España is essentially the Spanish registry which includes the data on the pollutants or emissions to water, which also serves to complete the European registry of (EEA, 2010. European Pollutant Emission Register (EPER), EPER_dataset_15-08-2008. European Environmental Agency..

information of revenue, which is the variable (the share of sectoral revenue) used to apportion the rest of the grey water footprint by sector (NACE classification[8] with which we homogenized the input-output tables for the MRIO) and region when the former is not available. Since we did not know the abstractions and effluents by particular businesses, the grey water footprint of these businesses with info on emissions to water was estimated directly by the value of the load of pollutant emitted divided again by the difference between the maximum and natural concentration of the limiting pollutant (the one resulting with the highest GWF of the business). Once identified those business with emissions to water and their GWFs, by sector and region, the rest of the business GWFs were apportioned with the revenue information by sector and region from the regional GWFs of production. This geo-referenced industrial database[9] allows us to relate the MRIO framework to territorial information and to other geographical characteristics such as the basin, river, water masses, and vulnerable and sensitive areas data, in order to assess the most risky areas.

In particular, the main additional information with which we link the layers on business, emissions to water and grey water footprints of production are, firstly, the data on water, such as river flows, water masses and especially water run-off which we compute at the regional level, and we choose in order to compare and obtain different indicators that compare the theoretical water requirements (water volume for assimilating waste based on ambient water quality standards) with actual water availabilities. A first estimation of water availability is obtained as natural run-off for an average year in the period 2000-2010, obtained from (MAGRAM, 2015; SIMPA, 2010). This information, as it occurs with the original data of precipitation and real or potential evapotranspiration, is obtained monthly, and can be summarized by gird cell (1km by 1km) or aggregated at higher levels. In a second estimation, we obtained the Potential Availability of Renewable Water Resources (PARWR) for an average year in the same period, where we consider the potential water availability, departing from the above run-off in the following way:

$$\text{PARWR} = \text{Natural run-off} - \text{Environmental reserve} + \text{reuse \& desalination} \pm \text{Water transfers}$$

This run-off then accounts already for the fact that some water cannot be used for economic purposes due to necessary environmental reserve (assumed essentially at the 10% of the

[8] NACE -- Classification of Economic Activities in the European Community (Nomenclature des Activités Économiques dans la Communauté Européenne).

[9] Other economic detailed data has been obtained by Döll, P., Muller, J.P., Elvidge, C.D., 2000. Nighttime imagery as a tool for global mapping of socioeconomic parameters and greenhouse gas emissions. Ambio 29, 157-162., Sutton, P.C., Costanza, R., 2002. Global estimates of market and non-market values derived from nighttime satellite imagery, land cover, and ecosystem service evaluation. Ecological Economics 41, 509-527, Sutton, P.C., Elvidge, C.D., Ghosh, T., 2007. Estimation of gross domestic product at sub-national scales using nighttime satellite imagery. International Journal of Ecological Economics and Statistics 8, 5-21., the Global Risk Data Platform UNEP/GRID, 2013. Global Risk Data Platform. UNEP/GRID-Geneva (in compliance with Open Geospatial Consortium). Supported by UNISDR., Ghosh, T., Powell, R., Elvidge, C.D., Baugh, K.E., Sutton, P.C., Anderson, S., 2010. Shedding light on the global distribution of economic activity. The Open Geography Journal 3, 148-161.; and Nordhaus, W., 2006. New Data and New Findings. Proceedings of the National Academy of Sciences 103, 3510-3517.. On the one hand, the latter has less resolution than the former (1 degree Longitude/Latitude rather than 30 arc-seconds), but on the other hand it uses population data (rural/urban) as well as income/labour data (regional by industry), land area, and some estimates of minerals production, from statistical agencies. The main advantage of the database we use (SABI, 2013) is that we obtain the economic information by business, knowing its sectoral classification, being then possible to link their aggregation to the sectoral aggregation of the input-output tables.

natural flow, see (MMA, 2011a)), necessary minimum flows flowing internationally (to Portugal, (MAPA, 2000)), the water transfers and the reuse and desalination (from capacity, (MMA, 2011a, b)). Map S1 in this Supplementary Information shows the regional distribution of PARWR per surface area.

Secondly, since we can look closer than the regional level at the areas with the highest grey water footprint of production, we also look at the local vulnerable areas to nitrates data as defined in the Directive (91/676/CEE, 1991) which are, or may become, in a state of eutrophication, and sensitive areas as defined in the Directive (91/271/CEE, 1991) concerning the treatment of urban wastewater. This particular information obtained from (MMA, 2011b) has been selected in order to identify a final indicator on the comparison of grey water footprint of production and its change with meso and macro policies to local vulnerable and sensitive areas, which are, with limitations, the best official sustainability and assessment indicators or mappings of water quality risks. The information (MAGRAM, 2015; SIMPA, 2010) of rivers, and water bodies (mainly lakes for the information of phosphorus) is key to understand the locations of nutrient concentration, to estimate and represent water availability, transfers and desalination.

In the case of the desalination plants, the data file at the municipal level allows to observe how they are mostly located in the islands (especially in the Canary islands), south of Spain (Guadalquivir catchment, in Andalusia, and at the origin of the Guadiana catchment, in Castile-La Mancha), and notably in the southeastern Mediterranean coast, more importantly around the region of Murcia. In the case of the water transfers, the information comes from Spanish Ministry of Environment, Rural and Marine, but the interregional transfers are not so common despite the existing interbasin transfers (e.g. the Ebro basin has 8 water transfers to other basins, and receives one from the Duero basin[10]). The main exception is the main water transfer in Spain of Tajo-Júcar-Segura (Castile La-Mancha, essentially to Murcia, and partially to Andalusia and the Valencian community), but most other transfers (Negratín-Almanzora in Andalusia, Ebro-Besaya in Cantabria, Zadorra-Arratia-Ebro to Bilbao in the Basque Country, or even the Ebro-Tarragona in Catalonia, at the most affecting Aragon) are intraregional. We also use complementary information to locate or verify the areas of agriculture, industries and services (Corine land cover 2006, (EEA, 1992), (Büttner et al., 2004; Büttner and Kosztra, 2007). In this sense, the main areas of agrarian production, by crop production, are distinguished from the pasturelands and the other land uses.

As discussed in the final section of the manuscript, the methodological choices (e.g. accounting of industrial grey water footprints), the choice of data and number of pollutants leaching as non-point source pollution, and other data limitations condition the computations. Our objectives is though, rather than center the article on this reflections on the uncertainties and ranges found for the different variables and results, more focused on identifying the relative spatial location of grey water footprints of production, linked to vulnerable and water scarce areas, and to the final demands that pull that production. Relative high levels of water required to assimilate pollution in water scarce might be a reason for concern, and so it is the fact that increasing demands may pull more of polluting production through virtual water trade. For that reason the interregional and supply chain links described at the beginning of the section are emphasized in the results in the Manuscript.

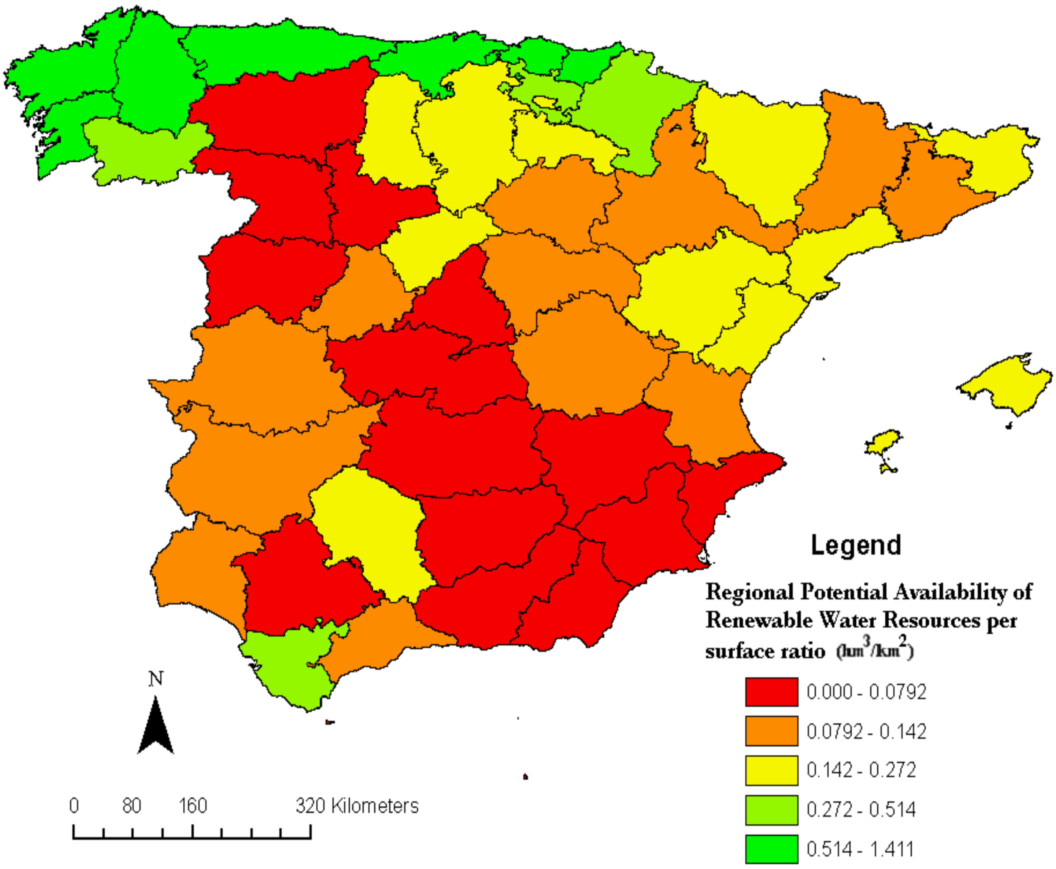
[10] http://www.chebro.es/contenido.visualizar.do?idContenido=2157&idMenu=2228

Table S1: Data of businesses from SABI by ARs

Autonomous Region	nº of companies	nº of workers	Revenues (million EUR)	Direct grey water of all sectors (hm^3)	Sector with the highest number of workers	Sector with the highest % of companies with respect to other regions
Andalucía	17,444	591,350	90,112	11,527	Construction	Agriculture, hunting,
Aragón	3,361	140,312	29,226	4,951	Manufacture of motor	Manufacture of
Castilla La	5,238	145,809	23,570	6,558	Construction	Dairies
Asturias	2,664	102,821	23,209	1,793	Construction	Metallurgy
Baleares	3,619	145,712	20,327	1,366	Hotels	Hotels
Canarias	5,458	215,430	28,888	3,046	Hotels	Househ. employ
Cantabria	1,493	52,003	9,808	1,209	Construction	Dairies
Castilla y León	6,173	213,072	38,463	13,685	Construction	Meat Industry
Cataluña	31,848	1,570,402	333,990	8,990	Wholesale trade and	Chemical Industry
Galicia	7,652	311,412	63,876	3,862	Retail trade, repair of	Extraction of energy
La Rioja	811	24,262	4,562	632	Construction	Beverages & tobacco
Madrid	27,421	2,653,294	664,547	5,801	Public administration	Insurances and
Navarra	1,571	80,580	21,864	2,488	Manufacture of motor	Manufacture of
País Vasco	8,002	415,729	95,344	2,435	Public administration	Metallurgy
Extremadura	2,247	63,487	9,034	2,746	Construction	Meat Industry
Murcia,CyM	4,225	176,630	26,663	1,610	Wholesale trade	Agriculture, hunting,
Valencia	15,820	632,695	114,529	7,902	Retail trade, repair of	Textile industry &
Total	**145,047**	**7,535,000**	**1,598,009**	**80,601**	**Construction**	**-**

Source: Own elaboration from (SABI, 2013).

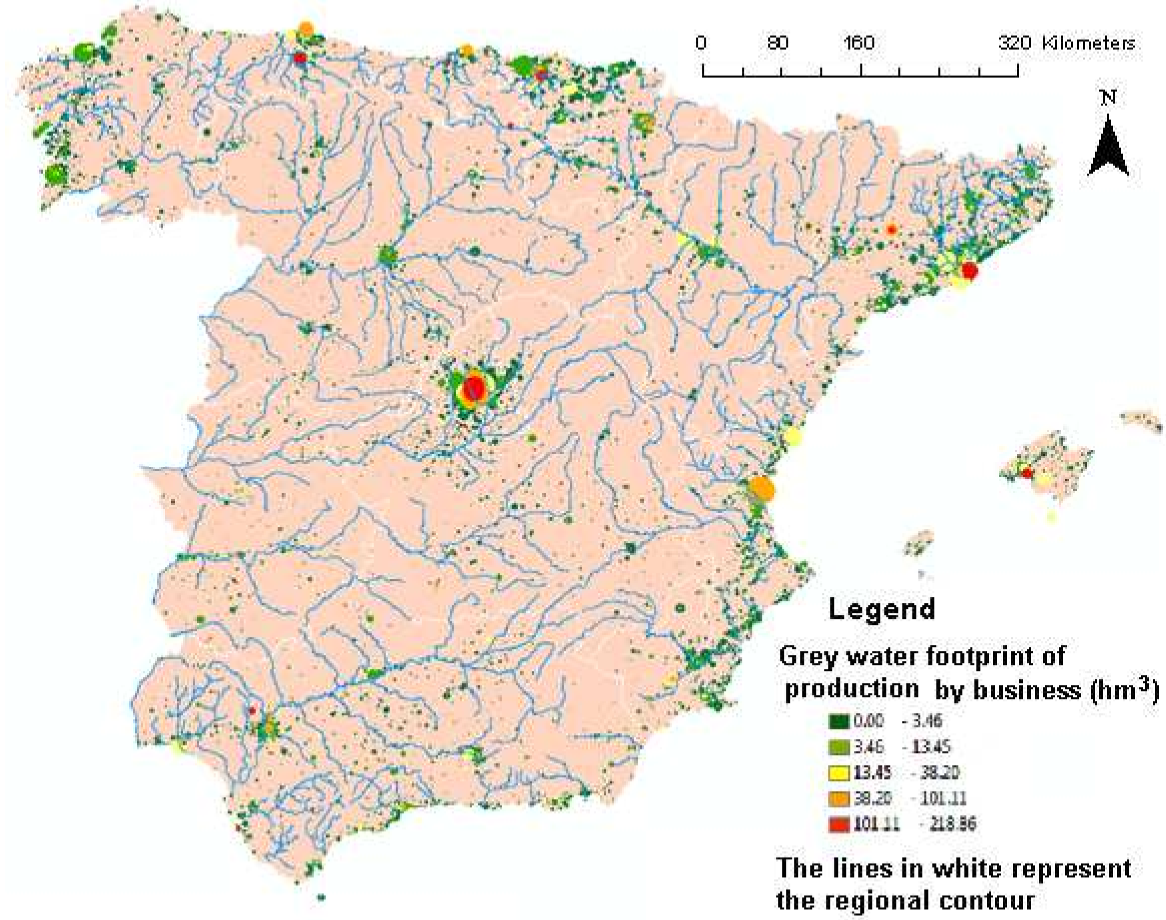
Map S1: Regional Potential Availability of Renewable Water Resources (PARWR) per surface ratio



Note: Method of ranges division: Natural breaks.

Source: Own elaboration based on (MAGRAM, 2015; SIMPA, 2010).

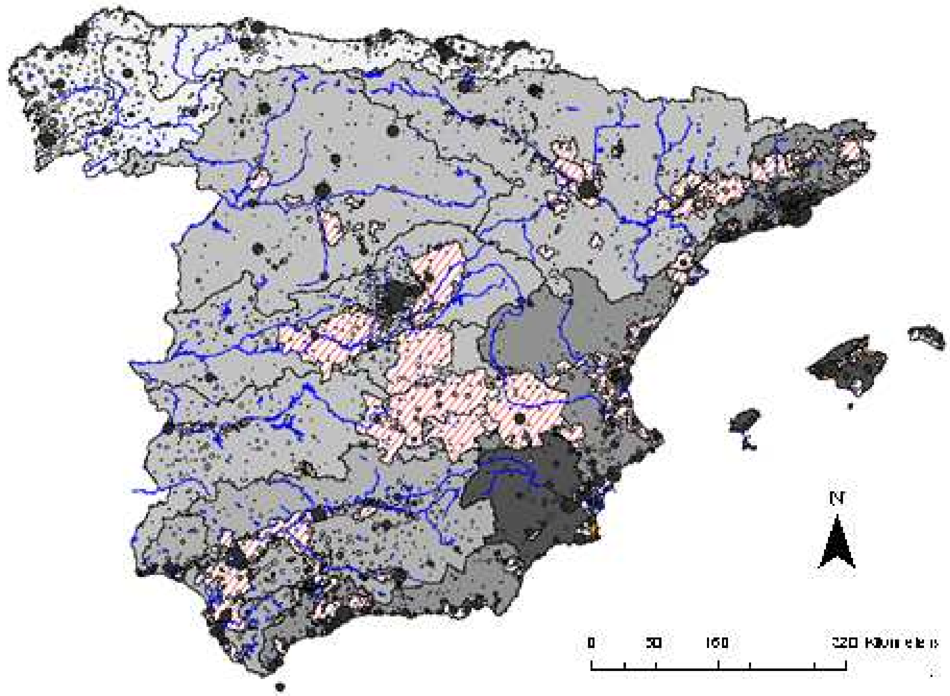
Map S2. Localization of business according to their direct grey water (size of spheres by turnover).



The grey water of production by business is shown by the green (less grey water)-yellow-red (more) scale, bringing forward the hotspots of the highest Grey water footprint of production.
The size of the spheres represents the size of the business (of a particular enterprise, measured by the turnover).
Regions (ARs) are delimited in white, and rivers and reservoirs are shown in blue.

Source: Own elaboration, with databases on rivers.
http://servicios2.marm.es/sia/visualizacion/descargas/mapas.jsp

Map S3: Grey water footprint of production to natural water availability (run-off) ratio



Note: The natural water availability (run-off) is accounted by hydrographical demarcation.

Source: Own elaboration, using the databases on run-off (MMA, 2011b) rivers and vulnerable and sensible areas. http://servicios2.marm.es/sia/visualizacion/descargas/mapas.jsp

Table S2: Embodied grey water. Specific sectoral distribution

Sectors \ Regions	Andalusia	Aragon	Castile-La Mancha	Asturias	Baleares	Canarias	Cantabria	Castile and León	Catalonia	Galicia	La Rioja	Madrid	Navarre	Basque Country	Extremadura	Murcia, Ceuta & M.	Valencian C.
Agriculture, hunting, fishing and related services	846	262	855	86	128	354	164	1,150	1,987	589	140	3,267	370	1,599	428	791	1,131
Extraction of energy products and refining	287	23	2	20	136	92	28	26	186	50	0	244	12	162	140	134	117
Production and distribution of electricity and gas	135	42	100	91	23	129	40	64	200	59	7	0*	32	225	22	41	143
Collection, purification and distribution of water	20	8	8	1	3	8	2	9	17	2	1	0*	1	5	4	8	4
Meat industry	737	218	201	140	102	178	104	759	1,222	367	25	906	130	588	286	467	613
Dairies	280	147	85	50	59	73	52	204	456	171	22	404	38	225	151	252	295
Other food industries	174	147	227	114	114	289	47	298	1,576	420	48	785	172	477	128	279	1,173
Beverages and tobacco	482	36	68	17	71	102	17	82	143	70	13	202	23	69	149	315	207
Textile, clothing and leather	259	100	148	62	44	149	48	151	490	175	14	428	51	204	99	201	350
Manufacture of wood and cork	7	-1**	1	1	0	0	1	7	11	3	0	0	3	5	38	3	7
Paper and printing	43	6	5	8	15	23	2	25	53	13	0	60	7	18	13	31	48
Chemical industry	87	12	29	21	30	46	10	23	166	54	12	140	15	55	22	50	95
Rubber and plastics	27	-3**	3	17	49	2	2	21	45	9	0	1	11	39	12	16	26
Non-metallic minerals	13	1	2	7	1	20	3	5	12	4	0	5	1	3	3	7	16
Metallurgy	8	0	0	17	0	0	5	1	0	1	0	3	-1**	4	3	7	1
Manufacture of metal products	27	9	13	4	0	11	3	23	45	9	2	160	7	25	4	8	16
Machinery and equipment	71	27	29	9	16	23	0	48	180	32	9	93	20	121	11	34	44
Manufacture of computer, electronic and optical	58	27	36	12	16	49	7	54	172	41	4	88	24	58	8	20	68
Manufacture of motor vehicles and other transport	137	61	74	34	44	116	47	62	365	117	13	526	27	72	29	68	140
Furniture and other manufacturing industries	92	12	25	14	19	40	10	58	125	41	4	105	13	33	20	43	71
Construction	1,141	299	137	149	133	523	113	317	585	238	56	921	94	323	130	169	500
Sale and repair of motor vehicles, trade in	86	14	11	25	12	78	16	23	134	29	2	46	15	28	13	15	24
Wholesale trade and commission	218	21	5	37	8	82	6	56	185	61	1	21	27	63	28	36	50
Retail trade, repair of personal effects	337	216	77	95	57	127	33	124	247	95	12	371	53	80	60	40	66
Hotels	79	42	17	37	151	528	40	300	268	61	7	660	104	55	12	14	131
Restaurants	2,283	473	189	395	467	738	287	708	2,581	738	165	984	240	575	387	339	1,380
Transportation	65	8	13	18	35	85	12	22	94	24	1	143	11	60	12	27	31
Transport-related Activities	10	11	2	11	39	30	1	10	84	12	0	66	6	10	1	2	13
Post and telecommunications	69	14	3	20	16	15	5	14	74	18	5	129	8	7	20	37	21
Financial intermediation and auxiliary activities	43	8	3	18	30	14	7	16	68	14	2	66	7	6	6	8	32
Insurance and pension	31	13	9	12	27	27	10	12	39	13	1	73	4	14	5	4	11
Real estate and related	340	149	31	83	62	197	57	55	302	70	8	385	29	123	55	32	164
Rental activities, computer and R D	31	12	3	3	4	68	6	24	60	13	3	6	6	11	4	8	25
Other Business	92	11	13	13	10	19	19	13	77	23	2	193	6	21	8	19	10
Education	175	36	13	42	23	77	39	43	154	39	8	294	22	46	28	23	90
Health, sanitation and social services	348	86	63	76	60	127	44	114	345	107	16	467	52	82	66	56	205
Arts, entertainment and recreation	230	34	11	25	74	80	13	78	195	56	8	806	28	57	27	24	51
Personal service activities	51	11	9	13	3	19	11	12	44	14	6	37	5	10	8	7	21
Public Administration	334	139	53	62	59	157	49	81	238	81	18	337	34	98	59	45	103
Households with employed persons	19	2	1	2	4	5	2	7	19	4	0	31	4	2	3	2	10
Total	**9,771**	**2,730**	**2,573**	**1,858**	**2,142**	**4,700**	**1,362**	**5,100**	**13,245**	**3,935**	**637**	**13,453**	**1,710**	**5,657**	**2,502**	**3,678**	**7,504**

* The absence of representation in the table used for Madrid of the sectors of Production and distribution of electricity and gas, and Collection, purification and distribution of water, impede us from deriving results on this.

** The exceptional case of the negative values for the embodied water contents in the sectors of Manufacture of wood and cork, and Rubber (in Aragon), or Metallurgy (Navarre), are due to the effect of variation of existences (superior to the final domestic demand in the year of study.

Source: Own Elaboration.

Table S3. Changes in the bilateral (double-entry) grey virtual water flows with the 20% of foreign and other Spanish import substitution of meat

	Andalusia	Aragon	Castile-La Mancha	Asturias	Balearic Islands	Canary Islands	Cantabria	Castile and León	Catalonia	Galicia	La Rioja	Madrid	Navarre	Basque Country	Extremadura	Murcia, Ceuta & M.	Valencian C.	EU	RW	Total grey water footprint of production (%)	Total grey water footprint of production (hm³)	Net Grey Virtual Water Export
Andalusia	4.6%	-9.4%	-0.5%	-2.9%	5.0%	-4.0%	-7.7%	-0.9%	5.3%	-2.3%	-3.9%	7.7%	-8.1%	-4.4%	2.2%	-0.9%	1.3%	3.2%	5.1%	**3.8%**	**436**	**500**
Aragon	-34.2%	13.8%	-11.7%	-47.4%	-60.8%	-35.5%	-25.6%	-12.6%	9.7%	-29.9%	-0.9%	3.8%	-18.2%	-33.3%	-41.9%	-9.4%	-23.3%	3.7%	0.2%	**1.4%**	**70**	**-78**
Castile-La Mancha	-7.4%	-14.3%	11.6%	-6.1%	-28.3%	-17.4%	-29.7%	-5.9%	-9.1%	-18.4%	-5.2%	-0.4%	-13.9%	-30.6%	-10.9%	11.7%	-8.5%	3.0%	8.6%	**1.4%**	**95**	**23**
Asturias	-5.1%	-2.6%	-3.1%	3.7%	-4.5%	-4.1%	-1.8%	-2.5%	-5.2%	-4.3%	-1.6%	-4.0%	-4.1%	-7.3%	-7.6%	-5.9%	-5.3%	0.0%	-1.3%	**1.3%**	**23**	**28**
Balearic Islands	3.4%	-2.8%	-2.2%	-2.4%	5.6%	-3.6%	-2.8%	-1.9%	-13.6%	-1.1%	-0.9%	0.1%	-7.6%	-6.9%	-4.4%	-2.7%	6.6%	0.8%	-0.9%	**3.3%**	**46**	**73**
Canary Islands	0.6%	-5.3%	-2.5%	-1.2%	-0.6%	4.1%	-0.2%	-1.0%	2.0%	-0.5%	-0.1%	6.6%	-2.6%	0.3%	-2.9%	-1.0%	4.5%	1.2%	0.1%	**3.7%**	**114**	**169**
Cantabria	-11.3%	-5.6%	-8.2%	-6.9%	-7.3%	-7.2%	4.0%	-0.4%	-8.9%	-9.6%	-4.1%	-9.8%	-14.9%	-24.7%	-20.7%	-14.7%	-11.3%	-1.0%	-2.2%	**-1.0%**	**-13**	**39**
Castile and Leon	-27.3%	-5.3%	-11.1%	-29.3%	-31.5%	-14.4%	-14.7%	6.5%	-32.1%	-27.4%	-15.1%	-2.9%	-10.5%	-18.7%	-19.8%	-35.2%	-30.2%	2.5%	-10.0%	**-8.8%**	**-1,218**	**-1,437**
Catalonia	-15.9%	-15.6%	-9.8%	-13.1%	-9.8%	-12.7%	-11.5%	-7.3%	4.0%	-10.7%	-6.0%	-10.2%	-23.7%	-23.2%	-20.3%	-21.9%	-16.4%	2.2%	-1.7%	**-1.4%**	**-129**	**86**
Galicia	-1.9%	6.6%	-6.6%	13.0%	-11.1%	-10.0%	-0.1%	1.3%	-0.8%	8.2%	-6.5%	11.0%	-2.9%	-8.3%	-18.5%	-16.4%	-9.2%	3.1%	-1.2%	**3.7%**	**144**	**182**
La Rioja	-14.3%	19.2%	-4.2%	5.6%	-23.3%	-12.2%	-4.0%	2.1%	2.7%	-5.6%	3.5%	10.1%	3.3%	1.1%	-25.4%	-25.5%	-18.0%	2.7%	0.0%	**2.0%**	**13**	**27**
Madrid	-1.9%	-1.8%	-1.3%	0.7%	-1.5%	-1.1%	-0.7%	-1.3%	-2.2%	-1.9%	-0.7%	6.1%	-2.7%	-4.7%	1.3%	-3.0%	-2.3%	0.1%	-0.9%	**2.8%**	**163**	**-86**
Navarre	-30.6%	-15.7%	-14.8%	3.2%	-31.6%	-18.1%	-35.6%	-14.6%	-30.3%	-16.5%	-0.2%	7.3%	29.5%	-16.8%	7.7%	-29.9%	-27.2%	0.5%	-6.6%	**-1.1%**	**-27**	**-152**
Basque Country	-1.0%	2.3%	-1.0%	-0.2%	-0.7%	-0.4%	1.5%	1.2%	-0.4%	-0.4%	2.3%	-0.6%	2.6%	7.7%	-5.8%	-1.6%	-1.1%	0.5%	0.2%	**4.1%**	**100**	**490**
Extremadura	2.6%	-1.5%	-3.6%	-2.6%	-13.2%	-9.4%	-2.6%	2.4%	3.9%	-11.6%	-3.8%	13.8%	-22.2%	-15.1%	9.6%	-12.7%	-7.9%	3.2%	1.1%	**4.7%**	**130**	**202**
Murcia C&M	-1.3%	-3.3%	-1.4%	-1.7%	-1.1%	-2.2%	-8.0%	-0.9%	-1.5%	-2.7%	-3.2%	0.0%	-1.0%	-5.5%	-1.2%	18.0%	-1.8%	-7.6%	0.3%	**2.5%**	**51**	**33**
Valencian C.	-2.6%	5.3%	1.2%	-3.7%	2.7%	-4.6%	-5.4%	-1.4%	3.3%	-5.0%	-3.5%	3.1%	-15.5%	-8.5%	-10.2%	6.8%	14.6%	3.3%	4.0%	**6.8%**	**552**	**478**
EU	-1.7%	6.4%	-11.2%	-2.3%	-4.8%	-4.6%	-7.0%	-1.8%	-3.5%	-0.4%	-2.4%	-1.7%	8.2%	-4.4%	-6.1%	-0.5%	-1.6%	-0.00%	-0.00%	**0.0%**	**-244**	**-409**
RW	-1.2%	0.7%	-3.6%	-1.4%	-3.4%	-9.0%	-6.9%	-1.9%	-0.8%	-0.2%	-3.8%	1.7%	-3.8%	-1.1%	1.3%	2.7%	1.4%	-0.00%	-0.00%	**0.0%**	**-250**	**-168**
Destination (%)	**-0.7%**	**5.4%**	**2.8%**	**-0.3%**	**-1.3%**	**-1.2%**	**-3.8%**	**4.3%**	**-1.6%**	**-1.0%**	**-2.3%**	**1.8%**	**7.3%**	**-6.9%**	**-2.9%**	**0.5%**	**1.0%**	**0.0%**	**0.0%**	**0.0%**		
WF of consum. (hm^3)	**-64.2**	**148.1**	**71.5**	**-5.5**	**-27.4**	**-55.2**	**-52.0**	**219.5**	**-215.4**	**-37.8**	**-14.5**	**248.4**	**124.8**	**-389.3**	**-72.5**	**18.1**	**74.7**	**171**	**-88**		**54**	**0**
Destination Spain (hm^3)	**-37.7**	**126.5**	**105.4**	**-0.5**	**-10.0**	**23.5**	**-39.1**	**229.7**	**-132.0**	**-34.3**	**-6.1**	**230.3**	**118.7**	**-350.0**	**-69.0**	**4.5**	**66.3**	**240.1**	**82.7**		**549**	**577**

* EU: European Union, RW: Rest of the world.

Source: Own elaboration.

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