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Socio-Economic Indicators for Water Management in the South-West Europe Territory: Sectorial Water Productivity and Intensity in Employment

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Abstract: Given the need for water use to be a crucial consideration in sustainable development, an adequate water allocation system across economic sectors is essential, especially in the face of increasing seasonal and perennial water scarcity. In an attempt to facilitate a socially and economically efficient adaptation to the climate emergency, we propose a set of eleven socio-economic indicators to analyze the current water management. This set of indicators could help to quantify the interrelationship between water use and its economic perspective, as well as its social perspective through its impact on employment. Any demand for water not only includes the direct use of water but also its indirect use, referred to as virtual water. This is the water indirectly used through the other inputs in the production process (input–output methodology). These indicators are evaluated in the South-West Europe territory where, in light of increasing water scarcity, there is a need to orientate water allocation toward employment with less intensive water use, to more water productivity and to less environmental impacts. The results at river basin scales show that water use is more productive in the tertiary than in the secondary and primary sectors.

Keywords: water productivity; water intensity in employment; direct water; virtual water; input–output methodology; SUDOE; SWAT

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1. Introduction

The term "sustainable development" appeared for the first time in the 1987 Brundtland report of the World Commission on Environment and Development to describe development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. The Brundtland report gave birth to the principles of sustainability that today permeate all United Nations (UN) programs. With respect to water issues, the UN-driven International Conference on Water and the Environment held in Dublin in 1992 established in the Dublin Statement on Water and Sustainable Development that "water has an economic value in all its competing uses and should be recognized as an economic good". It emphasized that "past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource" [2].

Nowadays, the main water problem in the EU is the increasing seasonal and perennial water scarcity because of demographic growth, economic activity, and climate change [3]. Over the past 59 years, there has been an EU-wide decrease of 17.6% in renewable water resources per capita [4]. There are large areas affected by overexploitation, and current trends show the possibility of increasing water stress [3]. In this context, water allocation, understood as the process of deciding how the available water is distributed to meet the needs of users, is fundamental. Young and Loomis [5] highlight the recommendation of the Dublin Statement [2] that water allocation policies should be analyzed with economic evaluation techniques, since estimating simulated market prices or shadow prices would help to guide efficient water allocation and investment decisions. As early as 2004, the literature mentions the idea that, in the face of global warming, having estimates of the economic values of increasingly scarce water resources may be an important step toward facilitating an economically efficient adaptation [6].

A first step toward approaching the water problem from an economic point of view lies in the use of water consumption indicators. One of these is the water footprint, defined as the volume of water used directly and indirectly to produce products and services consumed by the inhabitants of a country [7,8].

Yet, apart from the economic dimension and the unquestionable and necessary environmental dimension, the social dimension should also be considered. In fact, multi-criteria decision-making methods are normally used to address water allocation issues in a sustainable manner by considering various socio-economic and environmental factors [9]. In areas and periods of water scarcity, and in view of the climate emergency that we are facing, it is essential to consider the implications that water use in different economic sectors has on environmental and social issues. Water scarcity refers to the lack of sufficient water resources to meet water consumption demands in a region. Sustainable management can be achieved by reducing demand or by allocating water to uses that are more environmentally friendly and socially beneficial, in addition to socioeconomic development.

According to the water exploitation index (WEI+), a metric that takes account of net water consumption versus available renewable water resources, water scarcity is already a recurring issue in some parts of Europe [10]. Among the European regions that suffer or will suffer the most from water scarcity problems (measured in how many people live in areas with a WEI+ larger than 0.20 for at least 1 month per year), South-West Europe (SUDOE) is one of the most affected. Indeed, even in the most optimistic scenario it is projected that by the end of the 21st century the number affected will increase from 85 to 94 million people in the EU28 while, in an extreme warming scenario, this could reach 104 million (Mediterranean—robust) or potentially 295 million (EU28—less robust). In most of the SUDOE territory, the water stress baseline (ratio of total water withdrawals to available renewable surface and groundwater supplies) is high (40–80%) or even very high (>80%), expecting to reach a water stress 1.4 times higher in a "business as usual" scenario [3] (Figure 1).

In this context, our main objective is to develop economic indicators to quantify the impact of water on the economy of the regions at the river basin district scale in the SUDOE territory, using a set of three economic indicators based on water productivity in each of the existing economic sectors (primary, secondary, and tertiary). The aim is to determine the impact of each cubic meter of water in monetary terms in each of the sectors into which the economy of each SUDOE river basin district is divided. Water productivity in irrigated agriculture is usually measured in terms of quantity produced versus water used (kg/m^3) [11,12]. In our research, in order to make water productivity indicators comparable across different economic sectors, a common methodology is developed. This methodology consists of monetizing the indicators and expressing them in monetary units (EUR/m^3), based on the gross value added (GVA) which measures the value of goods and services produced in an economic sector.

The decision to allocate water based on economic productivity alone would neglect the social dimension of sustainable development, and so our second objective is to develop three social indicators that reflect the intensity of water use in the generation of employment by economic sectors and also at the river basin scale. This methodology reveals the number of cubic meters of water necessary for the generation and maintenance of each job in each economic sector. Booker and Trees [13] include the labor demand along with water productivity and technological innovations in response to water scarcity, but under the scope of crop switching.

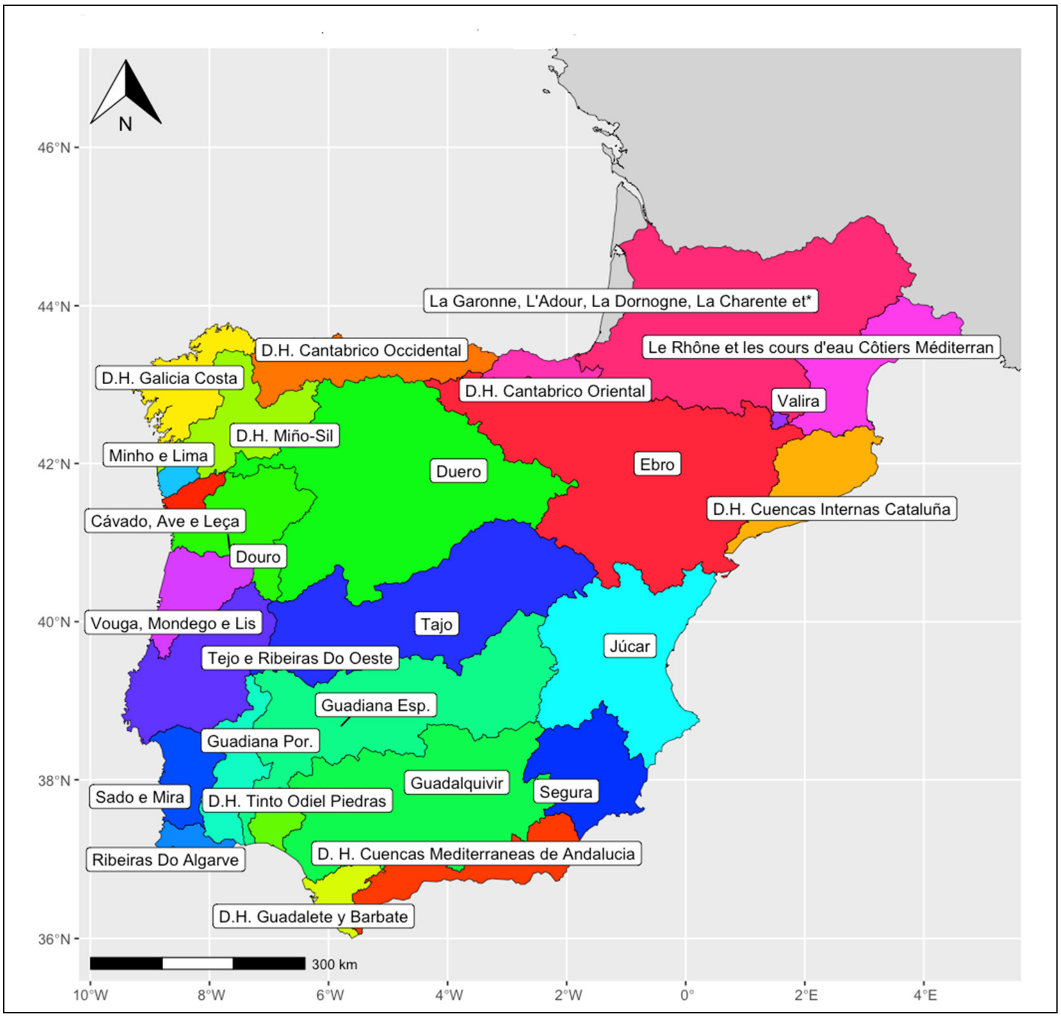


Figure 1. South-West Europe (SUDOE) territory.

This set of six indicators can be used by water managers to reduce the WEI+ by evaluating the difference in euros per cubic meter as well as cubic meters per employee used in the primary, secondary, and tertiary sectors in each river basin district.

The FAO report [14], which reviews the water situation worldwide, estimates that 70% of water is directly used for agriculture, particularly in irrigated agriculture, 22% for industrial production, 8% for domestic purposes, and 1% for recreational use. In Europe in 2017, water use was reported in agriculture (58%), energy cooling (18%), mining (11%), households (10%), and service industries (3%) [15]. We choose to focus on agriculture, since it is the largest water user and consumer base. The six indicators mentioned above are complemented by the creation of five indicators which measure water productivity in agricultural activities. The reason for dealing with indicators in agricultural activity separately from the primary sector is to study water productivity in more detail by distinguishing between rainwater and irrigation water, as well as rainfed and irrigated agriculture. This will help water managers to reduce the WEI+ by being aware of the euros per cubic meter spent in irrigated and rainfed agriculture, depending on the geographical area in which the river basin is located.

To truly assess the productivity and intensity of water use in each economic sector, the total amount of water required to create value for that sector must be considered, meaning that all water flows along the complex economic structure must be taken into account. The methodology based on an input–output framework makes it possible to calculate not only the direct water requirements associated with the production of each sector but also indirect ones [16]; that is, the water contained in the inputs that are involved in the production of a sector. Thus, the water imputed to each branch or sector of economic activity will only be that used for the production of final goods and services, and not that used in the production of intermediate consumption required by other activities.

It is this idea that gave rise to the concept of virtual water, first discussed in the 1990s [17,18]. Virtual water was initially defined as the water needed to produce agricultural commodities, although the concept has been expanded to include non-agricultural commodities through the supply chain [19]. Direct water denotes the actual consumption or withdrawal of water for specific purposes, such as irrigation, industrial processes, or domestic use. In contrast, virtual water refers to the water used in the production and trade of goods and services [20]. This encompasses the water utilized in the cultivation of crops, raising livestock, and manufacturing goods. Evaluating virtual water is essential for sustainable water management, particularly in regions grappling with water scarcity or contending with demands for water resources. A thorough understanding of both direct and virtual water is essential for assessing water footprints, sustaining water resources, and making informed decisions about consumption and production practices.

This article is divided into the following six sections. The first section contains the Introduction. The second section describes the study site, that of the SUDOE territory. The third section describes the methodology, including virtual water, indicators, and the transformation of scales from administrative to basin district levels. The fourth section shows the data sources, and the fifth section presents the results of the proposed economic and social indicators in the SUDOE territory. In the final section, the main conclusions, limitations, and future lines of research are discussed.

2. Study Site

South-West Europe, also called SUDOE, is composed of the south of France, Andorra, and the Iberian Peninsula (mainland Spain, Portugal, and Gibraltar) covering an area of nearly 780,000 km^2 (i.e., approximately 25% of the EU total) (Figure 1) and a total population of 61.3 million inhabitants (i.e., 16% approximately of the EU total). SUDOE is an inland peripheral territory with interconnected demographic (rural depopulation and aging) and territorial (urban–rural and center–periphery interconnections) characteristics and unique environmental conditions. Within SUDOE are regions which are expected to suffer increased stress of 20% or more on water resources in the future.

The territory brings together major European cities, including two capitals (Madrid and Lisbon) situated within the Tagus basin. The main climates are as follows: (1) the Mediterranean climate in most of the Iberian Peninsula and the east coast of southern France; (2) the temperate oceanic climate characteristic of the oceanic coastal regions of France, Portugal, and northern Spain; and (3) the Pyrenean mountain climate defined by a rain–snow regime [21,22]. The entire hydrographic network flows into the Atlantic Ocean or the Mediterranean Sea. This network is managed by the relevant administrations, which may differ by country and region.

With its temperate climate, land use in SUDOE is mainly dedicated to agriculture (50% of the surface area) and forestry (46%), but 3% of the territory is artificialized and hydrosystems represent 1% of the surface area [23]. SUDOE is the region of Europe with most agricultural activity, where intensive practices are often used. Agriculture represents an important part of the economy of SUDOE. The primary sector represents nearly 2.4% of the gross domestic product (GDP) of the Occitanie region and 4.1% of the Aquitaine region in France. The Mediterranean climate is conducive to cereal cultivation (38% of Spanish agriculture is made up of rice, corn, wheat, and rapeseed), olive groves (15%), and fruit trees and market gardening (15%). This agriculture is heavily irrigated, with 13.5% of agricultural lands in the SUDOE territory being permanently irrigated [24].

Cereals are the major crops in the three countries, but the French part of SUDOE also produces a lot of fodder crops, while the second dominant crop is market gardening for Spain and viticulture for Portugal. Irrigated cotton cultivation is widespread in Spain and Portugal and is even prevalent in the Andalusian region. A large part of the agricultural land is occupied by so-called rainfed crops without irrigation. In 2016, the French regions of Occitanie and Aquitaine had an average of 9.2% irrigated areas, while the Spanish and Portuguese regions had 22.2% and 26.1%, respectively, of their agricultural lands irrigated. In the driest regions, such as the Valencia region or Murcia in Spain, the practice of irrigation is intensive with more than 40% of agriculture being irrigated. Vegetables, orchards, soybeans, corn, and potatoes are the crops requiring the most water. In France, 45% of the irrigated area is used for corn, mainly due to the size of the total crop rotation. In total, 60% of the surface area of market gardening is irrigated. Cereal production represents a significant share of crops; 29%, 26%, and 12% for Spain, France, and Portugal, respectively (see Figure 2).

The European Soil Data Center (ESDAC) has listed the main soil types of SUDOE and their characteristics [25]. One of the most important soil types is Calcisol, a carbonated calcic soil which develops in arid areas, present in most of the SUDOE territory and in particular in Spain. Another soil type is Fluvisol, the alluvial or lacustrine soil characteristic of rivers, streams, and lakes, formed through the deposition of sediment; its composition therefore depends on the constitution of the downstream sediments and hydrological characteristics. Acrisol, located in the south-west of Spain, is a slightly saturated acidic clay soil, while Leptosol, in very eroded regions such as the Jucar region (eastern Spain) and the Spanish Pyrenees, is a hard and shallow limestone soil. Luvisol is a leached clay soil located mainly in the south of Portugal and the west of Spain. Lastly, Podzol is an acidic soil with an accumulation of organic matter of aluminum and iron characteristic of well-drained wetlands, found in the wetlands of Gironde (Aquitaine, France) and Évora (central Portugal).

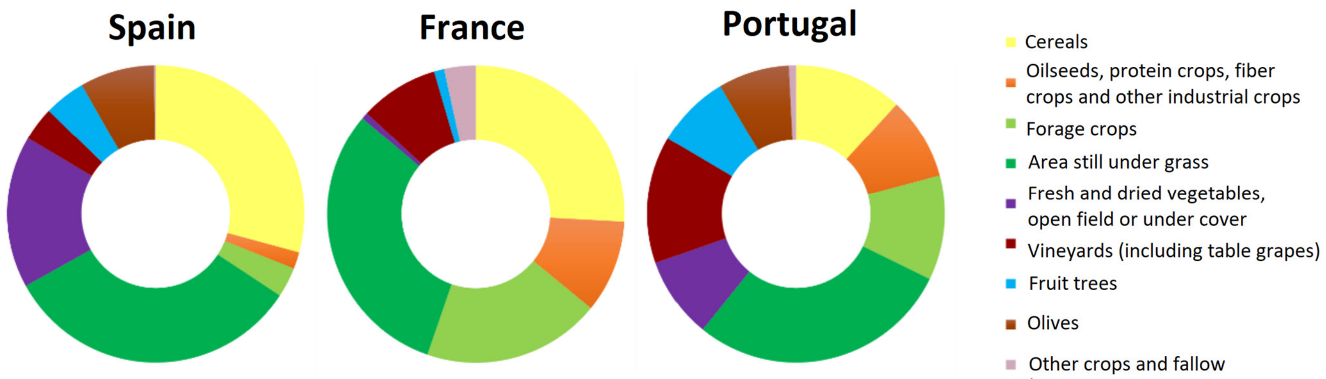


Figure 2. Distribution of the use of agricultural land by country in the south-west European zone according to national agricultural statistics data dating from 1998 to 2017. Source: Own elaboration with data from Agreste for France (2023), MAPAMA for Spain and INE for Portugal (2023) [26–28].

3. Methodology

3.1. Set of Indicators

We propose a set of indicators, related to productivity in the generation of value added and intensity of water use in employment, to compare the use of water in producing goods and services among different sectors and river basin districts. These indicators form a crucial tool for water management when assessing the economic and environmental impact of water use, in terms of water quantity. They can also help to identify opportunities for improvement in water allocation and use, and to promote more efficient practices, without neglecting the necessary consideration of the environmental impact of water use in each sector, in pollution terms. A higher productivity would mean the use of fewer water resources for the same level of production. Productivity is a concept closely related to efficiency. While efficiency is used to describe the effectiveness with which water is used to produce outputs, productivity is more concerned with the economic value of these outputs [29]. The water intensity in employment indicator adds the social component to the economic component and could be interpreted as representing the opposite of efficiency. Consequently, those sectors or basin districts with high intensity indices would need a greater amount of water to maintain the same level of employment.

3.1.1. Average Apparent Water Productivity by Sector

This subset of three indicators ($P_{prim.sec}$, $P_{second.sec}$, and $P_{tert.sec}$) measures the apparent productivity of water in all three sectors: the primary sector, which includes agriculture, livestock and forestry; the secondary sector, which includes industry and construction; and the tertiary sector (public administration, tourism, education, etc.). These are obtained by dividing the GVA generated by the economic sector by the amount of virtual water (the methodology for this is provided in Section 3.2) used for generating this GVA (Equation (1)).

$$P_{sector\ i} = \frac{GVA_{sector\ i}}{virtual\ water_{sector\ i}}, i = 1, 2; \text{unit}: \text{€}/\text{m}^3 \quad (1)$$

where sector 1 = primary sector (*prim.sec*); sector 2 = secondary sector (*second.sec*).

These indicators measure the units of GVA generated by a unit of water volume or, in other words, the euros produced with each m^3 of water dedicated to the economic activities. The qualifier "apparent" is added because water is not the only factor necessary for such production.

For the calculation of the indicator corresponding to the primary sector ($P_{prim.sec}$), the total GVA of the sector (agriculture, livestock, and forestry) and the amount of water used by livestock and forestry is needed. Data are obtained from official statistics for each country in SUDOE at the NUTS2 level. For calculating the volume of direct water used in the primary sector, a distinction must be made between the subsectors of agriculture, livestock, and forestry. For agriculture, direct water is calculated as the weighted sum of the amount of green water (which comes from precipitation and is retained in the soil) and blue water (from rivers, marshes, lakes, and aquifers), measured in cubic meters, which is needed to produce one ton of each type of crop, multiplied by the production (in tons) of each type of crop. For livestock, the calculation takes into account the total amount of blue water in cubic meters per head for each type of livestock, multiplied by the number of heads for each type. For forestry, the calculation considers green water, which is determined by taking the minimum value between the water requirements of the dominant species and the effective rainfall.

For the secondary sector, the direct water is considered to be the total volume of water captured by companies, whether through their own catchments or from the public water network.

In relation to the indicator for the tertiary sector (*tert.sec* in Equation (2)), it should be noted that in the denominator of the equation, water used in the sector also includes water for human consumption. The estimate of human consumption, based on the average consumption per inhabitant per day, includes private domestic use (food, washing, hygiene, etc.) and public domestic use (hospitals, schools, street cleaning, public fountains, garden irrigation, etc.). For this reason, it was decided to include domestic water together with the tertiary sector, as both data are merged and it is not possible to separate one from another. Unlike the other sectors analyzed, the calculation of direct water referring to human consumption is approached in a different way from the rest of the sectors analyzed, since it is not incorporated into the I-O model in the same way. This is because this volume of water is not subject to any type of water transaction by the other sectors, and the indirect water is always equal to zero.

$$P_{tert.sec} = \frac{GVA_{tert.sec}}{virtual\ water_{tert.sec} + water\ human\ comsumption}; \text{unit}: \text{€}/\text{m}^3 \quad (2)$$

3.1.2. Water Productivity in Agriculture

In addition to the indicators proposed in the previous sections, we also take a more in-depth look at the agricultural sector. To this end, five additional productivity indicators are proposed which consider the diversity of crop types (irrigated and rainfed) and the type of water (irrigation or effective rainfall): apparent water productivity in total agriculture (P_{agr}); average apparent water productivity of irrigation water in total agriculture (P_{agr_a}); average apparent water productivity in irrigated agriculture (P_{agr_b}); average apparent productivity of irrigation water in irrigated agriculture (P_{agr_c}); and average apparent rainfall water productivity in rainfed agriculture (P_{agr_d}). Note that in this case the water considered is always direct water, not virtual water.

The data corresponding to the water used in agriculture are obtained from hydrological models (SWAT) by considering the effective rainwater and irrigation water used by the plant for its optimal development (see Section 4.1 for more details). In the case of rainfed crops, only effective water is considered.

Average Apparent Water Productivity in Total Agriculture

The indicator (P_{agr}) measures water productivity in agriculture. It is obtained by dividing the GVA generated by this economic sector by the amount of direct water calculated through hydrological models (Equation (3)). It includes effective rainfall and irrigation water. Consequently, this indicator measures the units of GVA generated by a unit of water or, in this specific case, the euros generated by each m^3 of water dedicated to the above-mentioned economic activities. Calculation of this indicator requires the total economic value of the production of the agricultural sector from the river basin management bodies and the direct water used in agriculture.

$$P_{agr} = \frac{GVA_{agricultural\ sector}}{effective\ rainfall + irrigation\ water};\ \text{unit}: €/\text{m}^3 \tag{3}$$

The purpose of this indicator is to analyze the productivity obtained in each basin with the water it receives naturally (green water) plus the water it uses for irrigation (blue water). To do this, the amount of direct water used on crops must be estimated through SWAT modelling, including irrigation water and effective rainfall. This approach differs from the $P_{prim.sec}$ indicator in that P_{agr} quantifies and considers rainwater in the denominator, and $P_{prim.sec}$ considers not only agriculture, but also livestock and forestry. The aim is to see the productivity achieved in each basin district with the water obtained naturally plus the water used for irrigation. This, therefore, includes the economic value derived from the ecosystem service of each cubic meter of rainwater. The difference in water productivity between the north and south is given by the type of crops used (more valued or less valued) and the irrigation systems (more efficient or less efficient), since the amount of water in each location reflects the water requirement of the crops, whether the origin of the water is direct rainfall or irrigation.

Average Apparent Productivity of Irrigation Water in Total Agriculture

The particularity of this indicator (P_{agr_a}) (Equation (4)) is that only irrigation water is considered, excluding effective rainfall, since this is the water that costs money and that has a direct economic value.

$$P_{agr\_a} = \frac{GVA_{agricultural\ sector}}{irrigation\ water};\ \text{unit}:\ €/\text{m}^3 \tag{4}$$

This indicator enables the productivity that each basin can achieve from the irrigation water it uses to be calculated. We expect this to be higher in the north than in the south, since effective rainfall is not taken into account.

Average Apparent Water Productivity in Irrigated Agriculture

In this calculation, only the production of irrigated agriculture is considered, although the water use corresponds to both effective rainfall and irrigation water.

$$P_{agr\_b} = \frac{GVA_{irrigated\ agriculture}}{effective\ rainfall_{irrigated\ agriculture} + irrigation\ water}; \text{unit}: \text{€}/\text{m}^3 \quad (5)$$

P_{agr_b} (Equation (5)) should be understood as the productivity that irrigated crops present with the water they naturally have and the water provided by irrigation.

Average Apparent Productivity of Irrigation Water in Irrigated Agriculture

In this case, only the production of irrigated agriculture and irrigation water is considered.

$$P_{agr\_c} = \frac{GVA_{irrigated\ agriculture}}{irrigation\ water}; \text{unit}: \text{€}/\text{m}^3 \quad (6)$$

P_{agr_c} (Equation (6)) should be understood as the productivity that irrigated crops present solely from the water provided through irrigation.

Average Apparent Rainfall Water Productivity in Rainfed Agriculture

In this case, water productivity in rainfed agriculture is measured, so only effective rainfall is included as water (Equation (7)).

$$P_{agr\_d} = \frac{GVA_{rainfed\ agriculture}}{effective\ rainfall_{rainfed\ agriculture}}; \text{unit}: \text{€}/\text{m}^3 \quad (7)$$

Before constructing the indicators, we need to transform the information on direct water into virtual water in the case of productivity and intensity indicators for the primary, secondary, and tertiary sectors. This step is not necessary for the productivity sub-indicators in agriculture, since in these cases only direct water is used, i.e., only the water used directly in the production process is considered. The methodology for this transformation is detailed in Section 3.2.

It should also be noted that in the case of statistical information from official sources, such as water productivity and intensity indicators by economic sector, as well as GVA and employment, the data are available at the NUTS2 scale, so a methodology for scale transformation is necessary. This methodology, different according to the nature of each variable, is detailed in Section 3.3. In the case of water used for the agriculture indicators, no scale transformation is necessary, since these data are already generated at the river basin district scale in SWAT model outputs.

3.1.3. Intensity of Water Use in Employment by Sector

This set of three indicators ($I_{prim.sec}$, $I_{second.sec}$, and $I_{tert.sec}$) is defined as the volume of water used per full-time equivalent employee in an economic sector. It measures the pressure of the economy on water resources in relation to its impact on employment. Each indicator is obtained by dividing the amount of virtual water used in the economic sector by the number of full-time equivalent employed persons. This calculation requires the number of hours worked by the employed persons in the sector and the virtual water used in each of the economic sectors included in the sector. Equation (8) shows the formula for the primary and secondary sectors.

$$I_{sector\ i} = \frac{virtual\ water_{sector\ i}}{FTE_{sector\ i}}; \text{unit}: \text{m}^3/\text{employee} \quad (8)$$

where i = 1, 2; 1 = primary sector; and 2 = secondary sector. FTE means full-time equivalent employees. They have been estimated by dividing the hours worked by the annual average number of hours per full time employees.

As in the case of the productivity indicator, when considering water in the tertiary sector, water for human consumption is included (Equation (9)).

$$I_{tert.sec} = \frac{virtual\ water_{tert.sec} + water\ human\ comsumption}{FTE_{tert.sec}}; \text{unit}: \text{m}^3/\text{employee} \quad (9)$$

3.2. Direct and Virtual Water: I-O Method

As stated above, a definition of productivity could be the ratio between the GVA provided by a sector or branch of activity and the water used to produce it. However, the indicator of the intensity of water in employment is defined as the ratio between the water used by an economic activity and the employment linked to it. At this point, though, we should be careful to consider not only the water directly used in the production process (direct water), but also the water indirectly used through the rest of the inputs in the production process (indirect water). Virtual water (total amount of water used in the set of final products of a sector) is understood as the sum of direct water (the amount of water required exclusively in the production process) plus indirect water (the amount of water required in the production of other products used in the production process (inputs) minus the amount of water from the products that goes to other sectors (outputs)). Thus, the majority of direct consumption of water in the agricultural sector is used in obtaining the products that supply other sectors of Spanish industry [16]. To calculate the virtual water corresponding to the 25 activity branches at the NUTS2 level requires an additional methodological tool, an input–output model, which connects the different branches of activity [16,30–33].

In a global context, the use of interregional I-O matrices makes it possible to incorporate the import and export relationships of water embedded in goods between different regions or countries [34]. Here, we use I-O matrices for each of the NUTS2 administrative units of the south-west European territory (SUDOE). We work with I-O tables for 25 branches; this enables us to estimate the forward and backward flows of water between these branches.

In this way, we calculate the virtual water (**vw**), the sum of direct water (**w**) and indirect water used in each branch of activity, according to the expression shown in Equation (10),

$$\mathbf{vw}\prime = \mathbf{w}\prime(\mathbf{I} - \mathbf{A})^{-1} \quad (10)$$

where **w** is the vector of direct water with $\{w_i\}$ $i = 1, \ldots, 25$ standing for the volume of water used by each activity branch i per euro of its total production (x_i); **I** represents the identity matrix; and **A** represents the technical coefficient matrix of the input–output model (Equation (11)):

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \quad (11)$$

where **x** is the production and **y** the final demand, and $(\mathbf{I} - \mathbf{A})^{-1}$ the Leontief inverse.

The elements $\{a_{ij}\}$ show the quantity of inputs from sector i required to produce one unit of output in sector j. These coefficients have been updated using the RAS (row-and-column adjustment scaling) method. The use of the RAS method was popularized in the context of I-O analysis in the 1960s [35] and, despite its limitations, this algorithm remains the preferred option [36]. The RAS method assumes that the row and column sums of the input–output matrix, as well as the total production vector, are known. The algorithm iteratively adjusts the technical coefficients by multiplying them by diagonal matrices of row and column factors until they converge to a balanced matrix that matches the given row and column sums and the total production vector.

In this sense, if the technical coefficient a_{ij} is high, it means that sector j needs a lot of product from sector i to produce one unit of its own product and, therefore, the output of sector i has a large impact on the output of sector j and, consequently, a significant part of the water used by sector i in its production should actually be imputed to the production of sector j, since this water is being incorporated indirectly through the inputs coming from sector i.

3.3. Transformation of Scales: From Administrative to Basin District Levels

This section deals with the methodology used to make the necessary changes in scale to present the results at the basin district level. Firstly, it should be noted that these changes only need to be made for the information collected for the sectorial indicators (primary, secondary, and tertiary), since in the indicators of water productivity in the case of agriculture, the data are obtained directly from hydrological models at the required scale and do not need any transformation. We now describe the methodology used according to the type of information and indicator, with the criteria applied being adapted to each case.

For the direct and virtual water used in the primary sector, as well as for the GVA and employment generated in it, the information is transformed by pre-multiplication through a scale transformation matrix after aggregating the branches of activity corresponding to the sector. This matrix presents the basin districts in rows and the NUTS2 in columns and contains the share of irrigated area of each basin in each administrative unit or units, adding up to 100 in total for each administrative unit.

In the case of the secondary and tertiary sectors, there is a similar process for the transformation of direct and virtual water to the basin district scale, once the branches corresponding to each sector are aggregated, as well as human consumption water, GVA, and number of employees, the difference being that the transformation matrix includes the contribution of each basin in each administrative unit in terms of the number of inhabitants.

4. Data Sources

4.1. Water Data

The amount of direct water used in each production and domestic sector is obtained from official statistics (Instituto Nacional de Estadística in Spain, Agences de l'eau in France, and Instituto Nacional de Estatística in Portugal). For Spain, the 25 economic activity branches disaggregation list is considered, while for France and Portugal the information is only provided for primary, secondary, and tertiary sectors. Moreover, the information available in the different countries and used in this article is not entirely consistent in time. The most complete database between 2000 and 2015 (the latest year available for some of the series at the time of writing) has been used. Much of the data comes from survey data. For this reason, the average of the available information according to the economic sector and the country concerned has been used as a proxy and the results obtained should be considered as an estimate that nevertheless allows the highlighting of the applicability of the indicators and the value of the proposed social approach, albeit with its limitations. For more information, see Table A1 (in the Appendix A).

The volumes of direct and virtual water used in agriculture are determined through a simulation approach using the SWAT model. All pertinent details regarding the model and the extraction of irrigated water are outlined in [37]. Direct water is the water used for irrigation in agriculture, while virtual water is the water used for crop growth coming from the effective rainfall, i.e., the part of total rainfall used by the crops to grow. Virtual water is thus determined from SWAT model outputs as the difference before the real evapotranspiration volume minus the irrigation volume. Interannual average monthly irrigation and effective rainfall volumes are calculated from SWAT model outputs for the south of France, Portugal, and Spain. The model amalgamates irrigation information from diverse sources, including research institutes and national hydrological plans. Additionally, crop management data are gathered from national agricultural statistics databases and recommendations provided by agricultural organizations. The simulated irrigation volume is determined by the SWAT model [37], which considers parameters related to plant water demand and soil water content. Auto-irrigation is activated based on specific conditions for each crop and sub-basin, which vary according to regional areas. For calibration purposes, simulated irrigation volumes are compared with national statistical datasets to validate the model outputs. Crop management routing, simulated irrigation volume, crop yield, and biomass are calibrated and validated. Overall, the simulation results exhibit a commendable regional distribution of irrigated water, with high coefficients of determination (R^2 = 0.78) and low percent bias values (PBIAS = ±12.52), indicating the model's accurate representation of irrigation volumes in each SUDOE region [37]. The irrigation water simulated can be used for determining direct water indicators.

4.2. Socioeconomic Data

The following socioeconomic data were obtained from Eurostat at the NUTS2 level (see Table A2 in the Appendix A for more information): the gross valued added NACE data, needed for water productivity indicators ($P_{prim.sec}$, $P_{second.sec}$ and $P_{tert.sec}$); employment data, in terms of average hours worked per employee for water intensity indicators ($I_{prim.sec}$, $I_{second.sec}$ and $I_{tert.sec}$); and population statistics for human consumption.

5. Indicator Results at River Basin District Scale across the SUDOE Territory

5.1. Average Apparent Water Productivity by Sector

Figure 3 shows the average apparent water productivity in the primary sector ($P_{prim.sec}$), i.e., the production valued in euros generated for each m^3 of water used in agriculture, livestock, and forestry as a whole in each river basin district. In general terms, the north of the SUDOE territory has a much higher productivity than the central and southern river basin districts of the Iberian Peninsula. This is due to the rainy Cantabrian climate (>1100 mm/year), which means that the production-quantity water ratio is higher, i.e., for less water added to the production process, these regions can produce more. The importance of the fishing and livestock farming sectors in this area is also noteworthy. The French basins show the highest water productivity in this sector while the following central-southern peninsular areas show the lowest: Guadiana (in Spain and Portugal), Duero, Tagus, Júcar, and Ebro in Spain, as well as Minho, Lima, Sado, Mira, Cavado, Ave, and Leca in Portugal. However, the Cuencas Internas de Cataluña, as well as the Segura, the Guadalquivir and the basins of southern Andalusia together with the Portuguese demarcations of central-northern Portugal, have comparatively medium–low productivities. This is due to the type of production, with the olive and fruit and vegetable sectors in the south-east being more highly valued.

The industrial sector ($P_{second.sec}$) shows a higher water productivity than in the primary sector, with the highest values in the river basin districts of Galicia Costa and Valira, followed by the basins in the north of the Iberian Peninsula and Adour-Garonne (Figure 4a). Water productivity is very low in the industrial sector in the south of the peninsula, both in Spain and Portugal. However, water in the service sector ($P_{tert.sec}$) is the most productive in all regions, especially in the Adour-Garonne basin, followed by very high values in the north and center of the peninsula, up to the Tagus basin, which houses Madrid and Lisbon. The lowest values are seen in the Portuguese Guadiana River basin district (Figure 4b).

The comparison of water productivity in the river basin districts of the SUDOE territory in the three economic sectors is shown in Table 1 and Figure 5.

Table 1. Basic statistics of water productivity by economic sectors.

Basic Statistics	$P_{prim.sec}$	$P_{second.sec}$	$P_{tert.sec}$
Mean (EUR/m^3)	6.11	47.98	131.06
Median (EUR/m^3)	3.05	36.42	123.65
Standard deviation (EUR/m^3)	6.70	38.88	45.60
Coefficient of variation	1.10	0.81	0.35

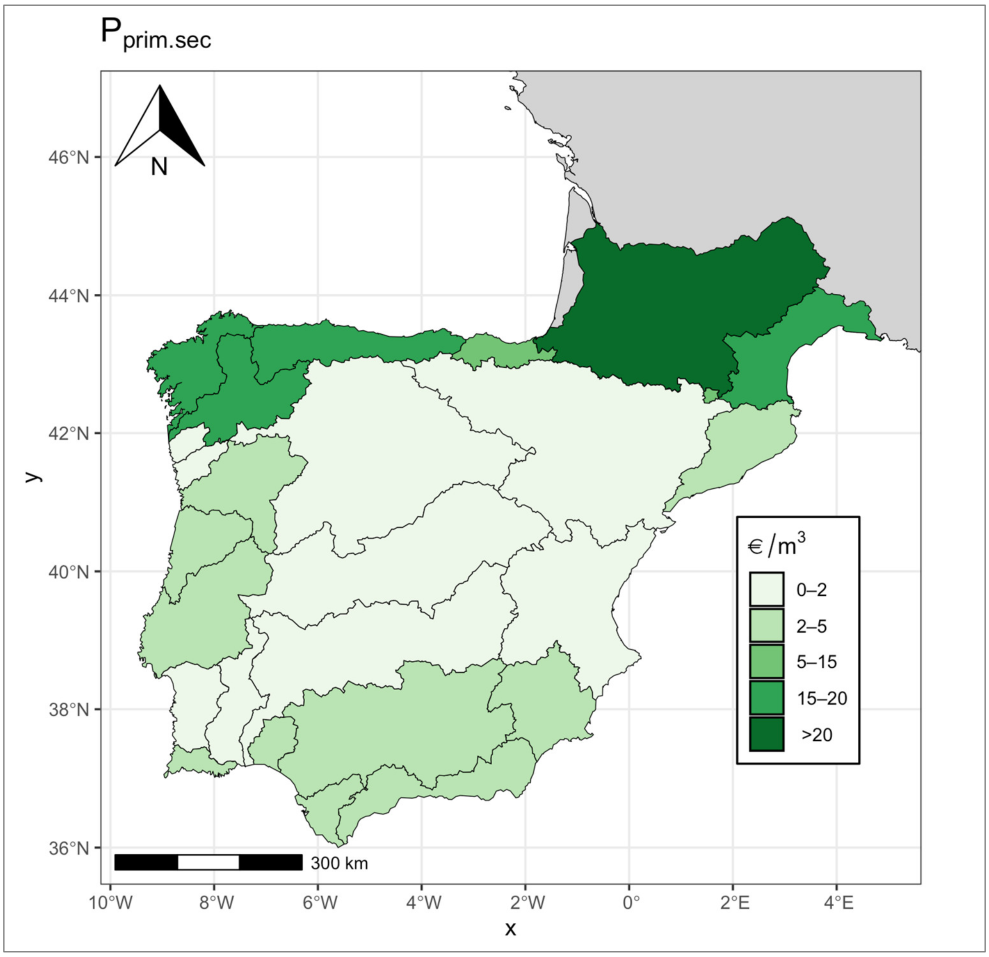
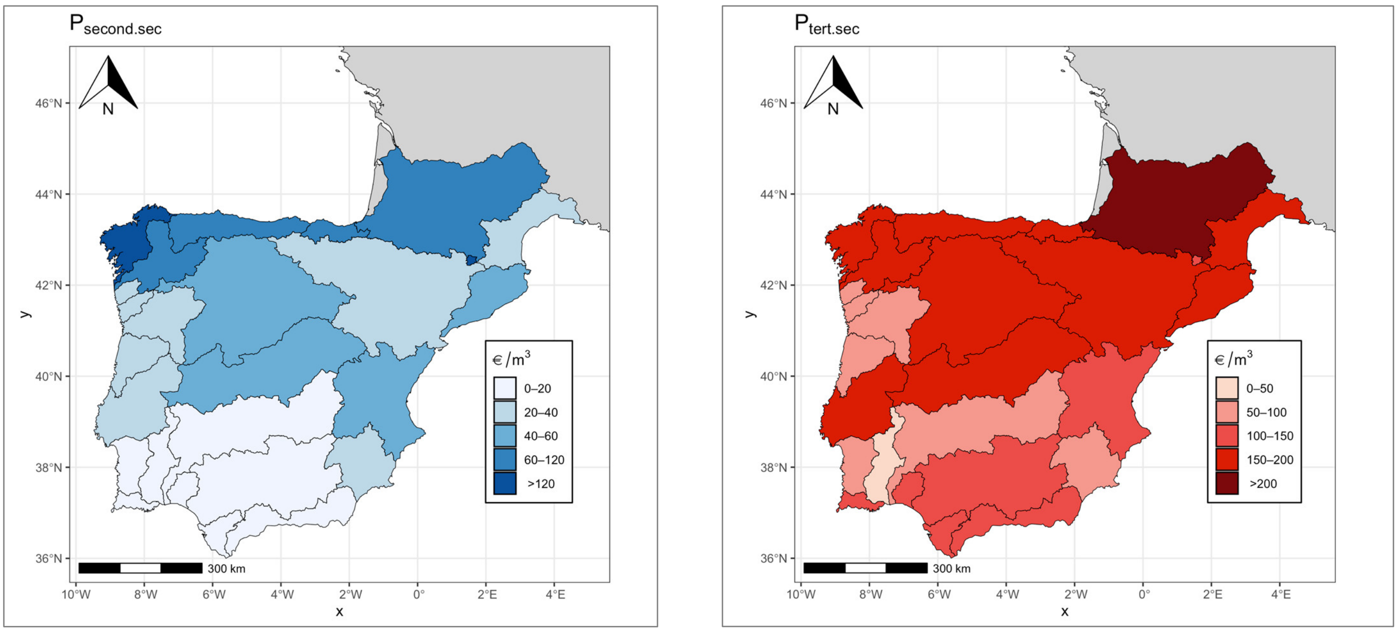


Figure 3. Average apparent water productivity in the primary sector ($P_{prim.sec}$).



(**a**) (**b**)

Figure 4. (**a**) Average apparent water productivity in the secondary sector ($P_{second.sec}$) and (**b**) in the tertiary sector ($P_{tert.sec}$).

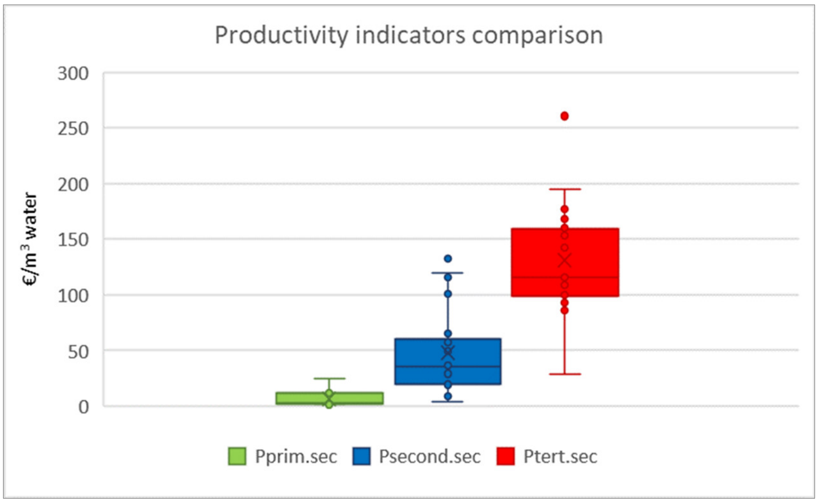


Figure 5. Comparison of water productivity indicators by economic sector.

5.2. Water Productivity in Agriculture

All the following results focus exclusively on agriculture (P_{agr}), as the economic sector which consumes the most water (68.5%) in the SUDOE territory (Figure 6).

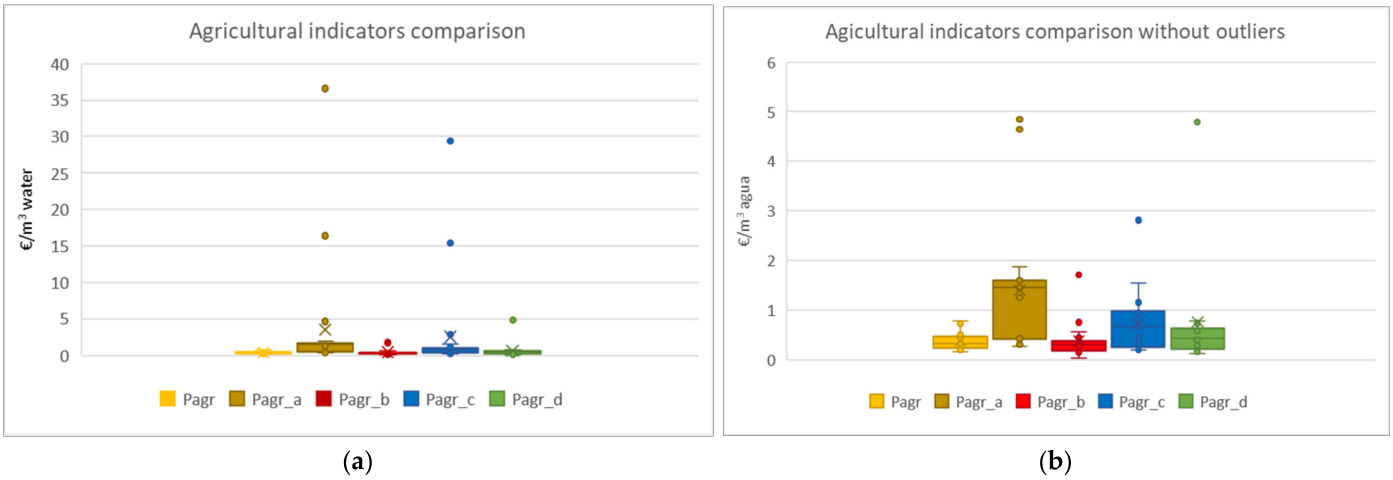


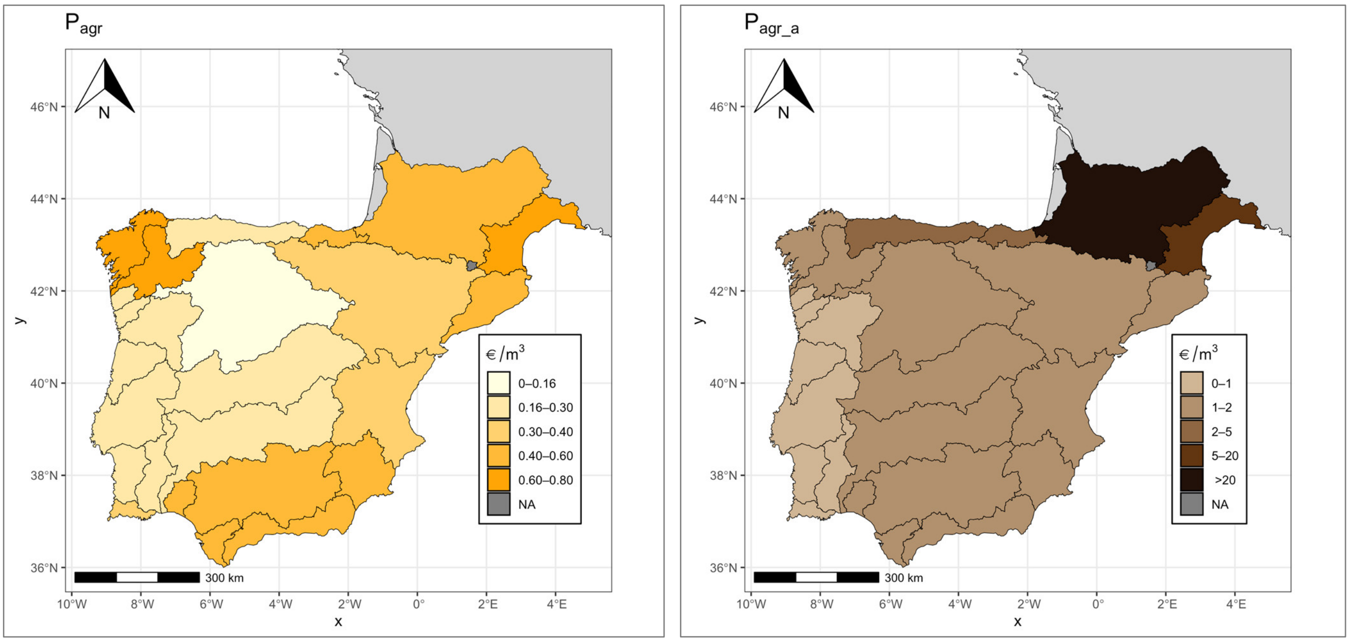
Figure 6. Comparison of agriculture indicators (**a**) with and (**b**) without outliers.

Table 2 shows, for the entire SUDOE territory, the highest agricultural productivity per m^3 of water, both in the mean and median, calculated with respect to irrigation water (P_{agr_a}) without counting the effective rainfall. This is a consequence of accounting for both irrigated and rainfed production and in rainy and dry climate zones for the additional water added to the crop, without accounting for rainfall. If direct rainwater (P_{agr}) is taken into account, the productivity per m^3 drops significantly. The average and median productivity of irrigated agriculture per cubic meter of irrigation water (P_{agr_c}) is higher than that of rainfed agriculture per amount of effective rainwater (P_{agr_d}). As is well known, contemporary agriculture generally obtains a higher economic return from irrigation water than from rainwater with rainfed products, all other factors influencing production being constant. Finally, the least productive option would be irrigated agriculture if, in addition to irrigation, direct rainfall (P_{agr_b}) is considered, i.e., if the importance of rainfall in irrigation yields is accounted for.

Table 2. Basic agricultural productivity statistics.

Basic Statistics	P_{agr}	P_{agr_a}	P_{agr_b}	P_{agr_c}	P_{agr_d}
Mean (EUR/m^3)	0.38	3.41	0.38	2.45	0.76
Median (EUR/m^3)	0.34	1.55	0.34	0.78	0.47
Standard deviation (EUR/m^3)	0.18	7.47	0.32	6.22	1.20
Coefficient of variation	0.48	2.19	0.86	2.54	1.58

Looking at the spatial differences of agricultural water productivity indicators, the P_{agr} indicator shows the highest values of mean apparent agricultural water productivity to be in Minho-Sil and Galicia Costa (north-west of the Iberian Peninsula), followed by small coastal Mediterranean rivers, in south-east France (Figure 7a), then rivers in south-west France, Cantabrico Oriental, Segura, the Cuencas Internas de Cataluña, and southern Spain. However, the productivity per cubic meter of water in agriculture in the Spanish Duero district is the lowest in the SUDOE territory.



(**a**) (**b**)

Figure 7. (**a**) Average apparent water productivity in total agriculture (P_{agr}); (**b**) Average apparent water productivity in irrigated agriculture (P_{agr_a}).

If effective rainfall is eliminated and water productivity in irrigated agriculture is measured exclusively through the P_{agr_a} indicator (Figure 7b), dividing by the amount of direct irrigation water used, the French regions are still those with the highest productivity per cubic meter of irrigated water, followed far behind by the Cantabrian coast. The productivity in the north-west region of Spain is reduced compared to the rest of the SUDOE territory. The Portuguese basins are seen to be the least productive per m^3 of water supplied by irrigation.

By considering only the production of irrigated agriculture in relation to the total amount of water received from irrigation and effective rainfall (see Figure 8a, indicator P_{agr_b}), the regions of the north-east of SUDOE and the Segura basin show a medium–low production, mainly dedicated to fruit and vegetable production. The north-west of SUDOE, including the north of Portugal, shows the lowest total irrigation productivity.

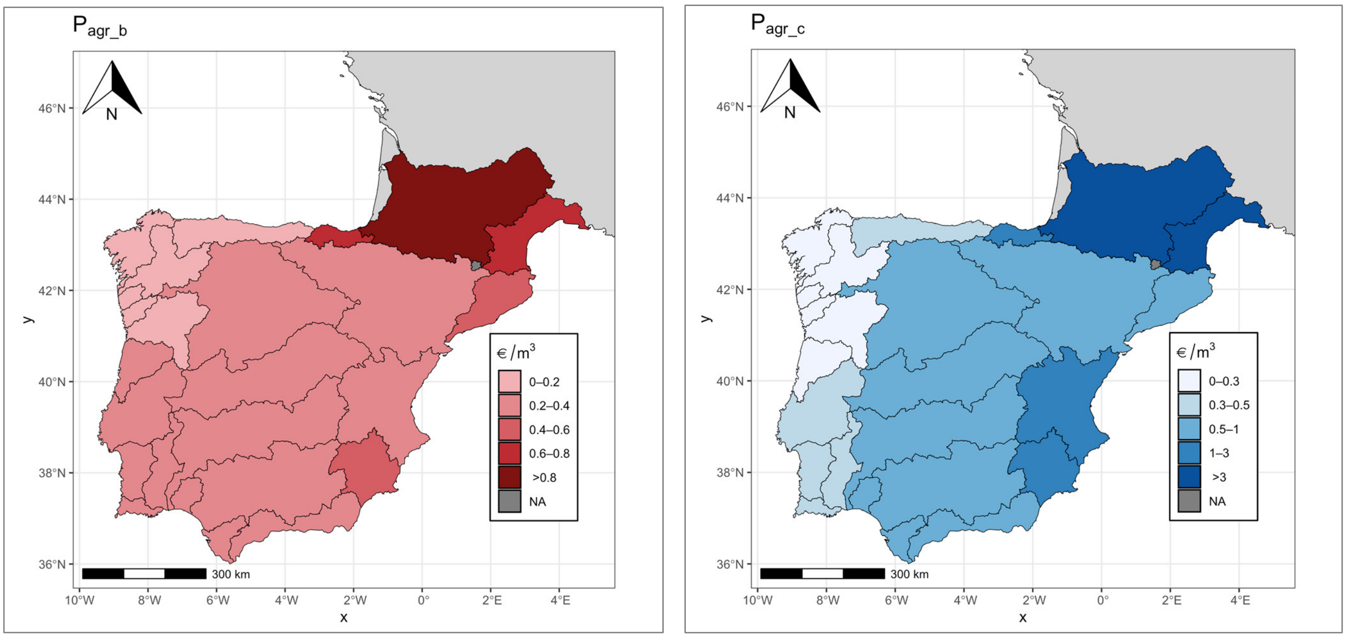


Figure 8. (**a**) Average apparent water productivity in irrigated agriculture (blue and green water) (P_{agr_b}); (**b**) Average apparent water productivity in irrigated agriculture (blue water) (P_{agr_c}).

If water from direct rainfall is eliminated and only water from irrigation is accounted for (Figure 8b, indicator P_{agr_c}), the productivity per m^3 obviously increases (with respect to Figure 8a, P_{agr_b}). The regions of southern France show high water productivity, followed by the Cantabrico Oriental and the basins of the rivers Júcar and Segura. The north-west area of SUDOE, including the Portuguese basins of the Vouga, Mondego, and Lis, shows the lowest irrigation productivity per cubic meter of irrigation water.

Lastly, we focus on rainfed crop productivity (Figure 9). The most productive areas per cubic meter of water are the demarcations of Galicia Costa and Minho-Sil, in the north-west of Spain, followed by the Cantabrico Occidental and the north of Portugal (Douro, Minho, and Lima, Cavado, Ave, and Leca). A lower rainfed productivity is seen in the south of France, the Spanish Douro and Tagus basins, and the Portuguese Guadiana, Sado, and Mira basins. An average dryland production is obtained in southern Spain, the Cuencas Internas de Cataluña, southern Portugal, and Vouga, Mondeigo, and Lis, in comparison to the SUDOE territory overall.

5.3. Intensity of Water Use in Employment by Sector

The last three indicators show the intensity of water use per employee in each of the economic sectors. These indicators measure the pressure of the economy on water resources in relation to its impact on employment.

The highest water use necessary to maintain a job, i.e., the highest intensity of water use per employee, is seen in the primary sector, followed by the secondary and tertiary sectors, respectively (Table 3 and Figure 10). In this primary sector, the highest values are seen in the Spanish basin districts of Duero, Tagus, Guadiana, Ebro, and Júcar and the lowest in the north and north-west of the SUDOE territory (Figure 11a). The highest intensity of water use per person employed is seen in the Guadiana district for the secondary sector (Figure 11b), and in the Guadiana and Segura districts for the tertiary sector (Figure 12).

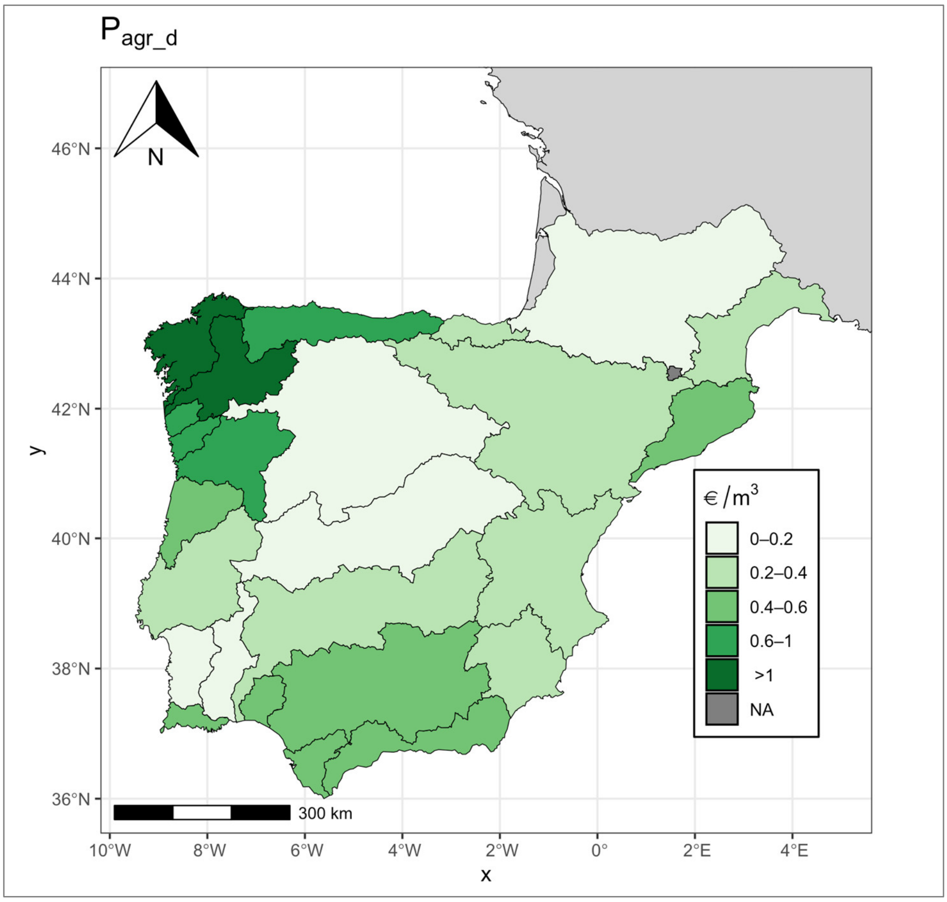


Figure 9. Average apparent water productivity in rainfed agriculture (green water is water that comes from rainfall and is retained in the soil) (P_{agr_d}).

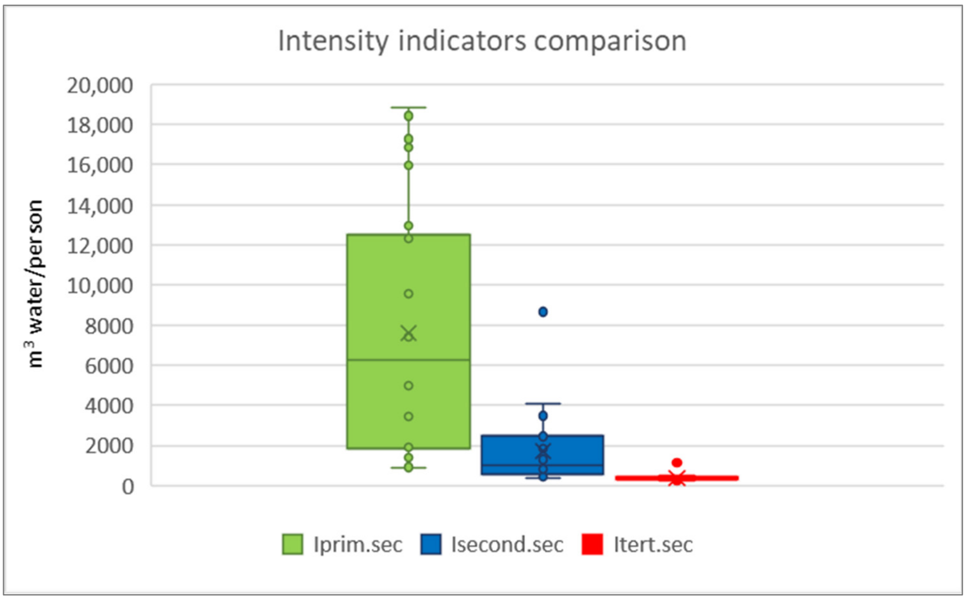


Figure 10. Comparison of water intensity indicators by economic sector.

Table 3. Basic statistics of water use intensity by economic sectors.

Basic Statistics	$I_{prim.sec}$	$I_{second.sec}$	$I_{tert.sec}$
Mean (m^3/employee)	7583.33	1711.35	397.78
Median (m^3/employee)	6240.15	1022.44	349.69
Standard deviation (m^3/employee)	6092.16	1700.01	170.97
Coefficient of variation	0.80	0.99	0.43

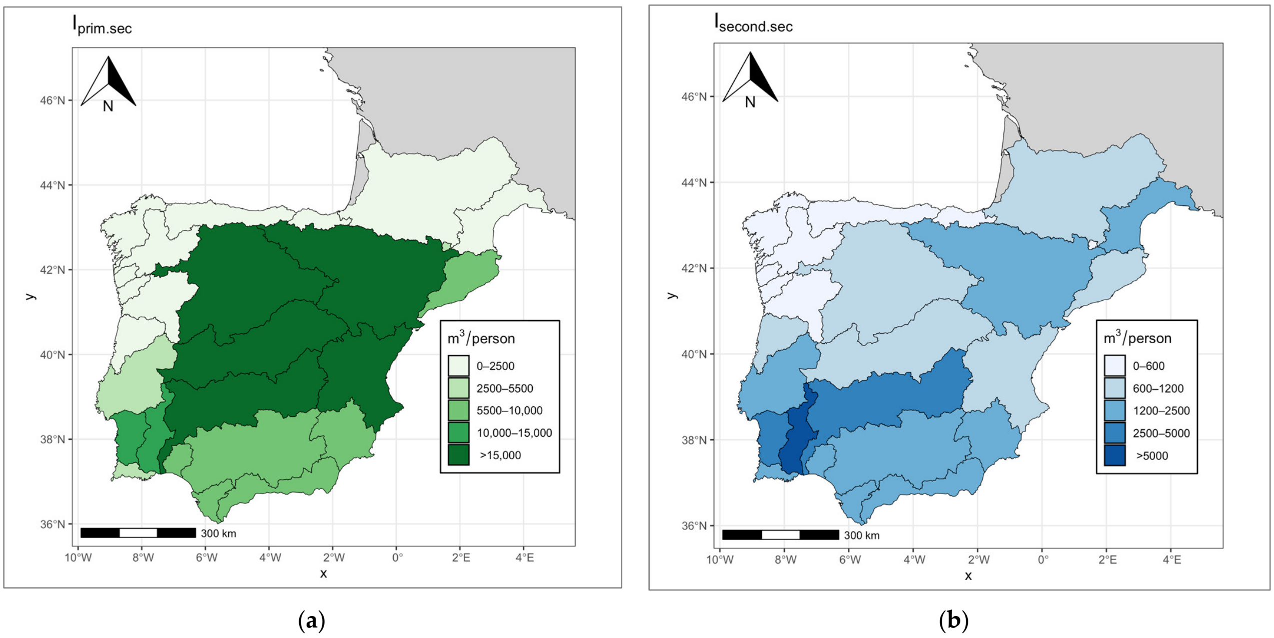


Figure 11. (**a**) Water use intensity per employee in the primary sector (m^3/person full-time equivalent employee) ($I_{prim.sec}$); (**b**) Water use intensity per employee in the secondary sector ($I_{second.sec}$).

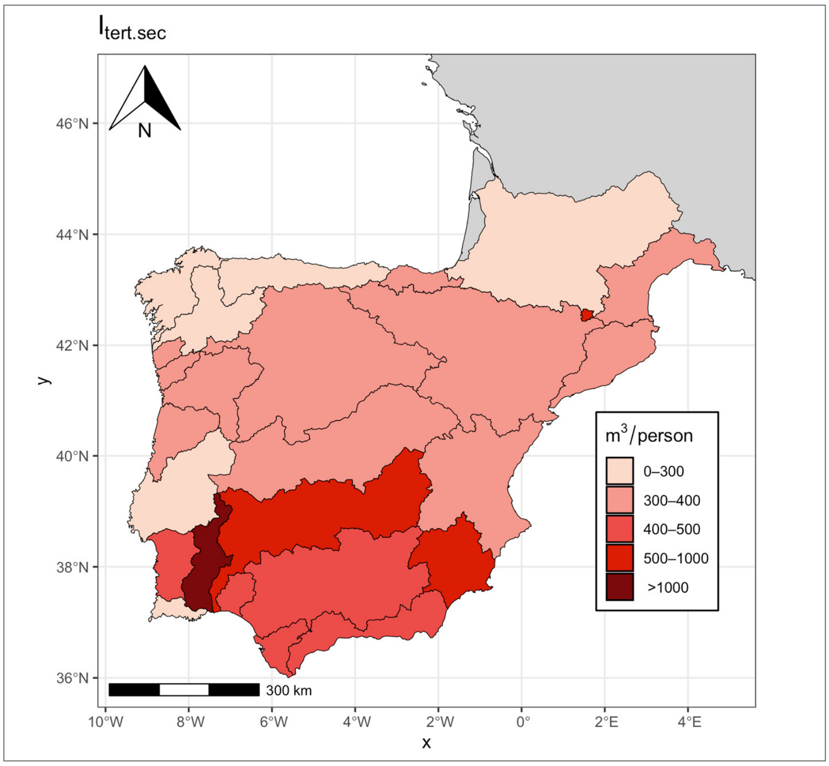


Figure 12. Intensity of water use per employee in the tertiary sector (m^3/person full-time equivalent employee) ($I_{tert.sec}$).

6. Discussion and Conclusions

With the aim of contributing from a methodological point of view to sustainable development in the European Union, in its first two pillars, the economic and the social in terms of employment, we propose a set of 11 socioeconomic indicators to evaluate the impact of water on the economy of the regions at river basin district scale in the South-West Europe territory. The first three and the last three indicators are selected to assess water productivity and intensity of water use in the generation of employment in the primary, secondary, and tertiary economic sectors; the last five indicators focus on water productivity in agricultural activities, both irrigated and rainfed. The reason for considering indicators specifically for agricultural activity separately from the primary sector is to obtain a deeper understanding of water productivity by distinguishing between rainfall and irrigation water, and thus rainfed and irrigated agriculture in the context of climate emergency water scarcity in SUDOE. We propose potentially important tools for water managers, since economically efficient river basin management calls for ways to measure the economic benefits or the monetary value of changes in water availability [5]. Any increase in water stress could have economic consequences.

Social, cultural, and environmental values relating to water are often in conflict with economic values [38,39], more so than for most other commodities. We propose three social indicators focusing on the employment and, more specifically, on the intensity of water use in the generation of employment by economic sectors. These three indicators can contribute to the design of water allocation policies which take into consideration social issues, in line with the study by Young and Loomis [5]. Our research also builds on the study by Booker and Trees [13] which includes the labor demand in a more microscopic approach focused on crop types, but without considering the possibility of allocating it to different economic sectors. In the near future, the quantity and quality of jobs that this amount of water is able to generate and sustain will be a crucial consideration in the decision of how to use the available water.

Results considering virtual water show that the north of the SUDOE territory has a much higher productivity in the primary sector than the central and southern river basin districts of the Iberian Peninsula. Industries, in general, show a higher water productivity than the primary sector with the highest values in the river basin district of Galicia Costa, while in the tertiary sector water is the most productive in all regions, especially in the Adour-Garonne basin. In the context of the climate emergency which particularly affects the middle-south of the SUDOE territory, based on these results, the establishment of new agricultural and livestock farms in these areas should be carefully analyzed, and a possible conversion of the agricultural and livestock sectors should be considered. Nevertheless, aspects such as the structure of the territory and the settlement of the population in rural areas, and the food security, among others, should be taken into account.

Focusing just on agriculture, which uses almost 70% of the total water resources, and considering direct water, the lowest productivity per cubic meter of water in agriculture in the SUDOE territory is found in the Spanish Duero district, mainly dedicated to rainfed crops. French regions obtain the highest productivity per cubic meter of irrigated water used, while the Portuguese basin districts appear as the least productive per m^3 of water supplied by irrigation. In irrigated agriculture, French river basin districts are more productive than in the south-east of Spain (Segura basin), both in blue water and in blue plus green water terms. However, the north-west area of SUDOE is the zone with the lowest irrigation productivity per cubic meter of irrigation water. Finally, the most productive rainfed areas per cubic meter of rainwater are the north-west of Spain, followed by Cantabrico Occidental and the north of Portugal. Note that, in general, in a water scarcity scenario, rainfed crops—although less productive—are preferable to irrigated, more productive crops. Nevertheless, it is a complex system for which, according to Booker and Trees [13], consideration of the interplay between water scarcity, agricultural production, and farm labor may be appropriate, starting from a framework of water development and agricultural development status, with a focus on specific consequential adaptations.

In social terms, the highest water usage that a job represents is found in the primary sector, in comparison to the secondary and tertiary sectors. These results, in a scenario of water scarcity, indicate the need to start reducing the volume of irrigation water in the least productive areas where employment signifies the highest intensity of water usage. The least efficient zone in terms of water required to keep someone employed in the primary sector is found in central Spain (Duero, Tagus, Guadiana, Ebro, and Júcar), with the Guadiana basin also being the least efficient basin in the secondary and tertiary sectors.

These indicators would include two of the basic pillars of sustainable development cited in the Brundtland report. With respect to the third pillar, the environment, we contribute to the environmental effect of water use, in terms of water quantity, but not in terms of quality of the water discharged into the environment after use. A future line of research would be to incorporate the mandatory ecological dimension in the decision making of where and how to allocate available water. Our study does not cover the environmental effects, in terms of water quality, of the way water is used in the various economic sectors, yet the ecological needs for water along some of the SUDOE rivers are still difficult to meet in areas with severe water scarcity, and practically impossible in others, such as the Tagus River basin. Despite the obligation for EU water bodies to reach and maintain a good ecological status by 2027 [40], the imbalance between ecological and socio-economic water use is still very much apparent [41].

Author Contributions: Conceptualization, B.L., N.G.-R., M.G., S.S. and J.M.S.P.; data curation, B.L. and N.G.-R.; formal analysis, B.L., N.G.-R., M.G., R.C. and M.R.; funding acquisition, J.M.S.P.; research, B.L., N.G.-R. and M.G.; methodology, B.L., N.G.-R. and M.G.; project administration, S.S. and J.M.S.P.; resources, B.L., N.G.-R. and M.G.; software, B.L., N.G.-R., M.G., R.C. and M.R.; supervision, B.L., N.G.-R., S.S. and J.M.S.P.; validation, S.S. and J.M.S.P.; writing—original draft, B.L. and N.G.-R.; writing—review and editing, B.L., N.G.-R., S.S., R.C., M.R. and J.M.S.P. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data sources can be found in Tables A1 and A2 in the Appendix A.

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Conflicts of Interest: Author Roxelane Cakir was employed by the company HETWA. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A

Table A1. Direct water data sources in SUDOE for primary, secondary, and tertiary economic sectors and domestic uses.

SPAIN			
	Economic Sector	**Period**	**Source**
Primary sector			
1	Agriculture	2000–2015	http://www.ine.es/jaxi/Tabla.htm?path=/t26/p067/p03/serie/l0/&file=02003.px&L=0, accessed on 12 March 2023
2	Livestock	2002–2015	https://porcinews.com/download/variacion-consumo-agua.pdf accessed on 12 March 2023 https://conservancy.umn.edu/bitstream/handle/11299/140901/1/Muhlbauer.pdf accessed on 12 March 2023

Table A1. *Cont.*

SPAIN			
	Economic Sector	**Period**	**Source**
			http://albeitar.portalveterinaria.com/noticia/3379/articulos-otros-temas-archivo/el-agua-y-su-importancia-para-los-b&oacutevidos.html accessed on 12 March 2023 https://www.agroterra.com/foro/foros/ganado-ganaderia-f10/cuanta-agua-bebe-una-vaca-al-dia-t18731.html accessed on 12 March 2023 http://mundo-pecuario.com/tema64/agua_nutricion_animal/requerimientos-398.html accessed on 12 March 2023 https://www.engormix.com/ovinos/articulos/evaluacion-consumo-agua-cabras-t29617.html accessed on 12 March 2023 https://ppryc.files.wordpress.com/2011/04/capitulo-3.pdf http://www.agroecologia.net/recursos/adge/articulos/agua%20ganaderia1%20jul-ago%2004.pdf accessed on 12 March 2023
3	Forestry	2001	https://www.mapa.gob.es/es/ accessed on 12 March 2023
4	Fishing	-	Non available
Secondary sector			
5	Extractive Industries	2005–2015	https://www.miteco.gob.es/es/energia/mineria-explosivos/estadistica/consulta.html accessed on 24 March 2023
6	Food, meat and dairy industries	2006–2010	
7	Other Industry, Food: tobacco and beverages	2006–2010	
8	Textile industry	2006–2010	
9	Wood Industry	2006–2010	
10	Paper Industry	2006–2010	
11	Petroleum refining and Nuclear	2006–2010	
12	Chemical industry	2006–2010	www.ine.es/daco/daco42/ambiente/aguaindu/uso_agua_indu0710.pdf accessed on 24 March 2023
13	Rubber and Plastics Industry	2006–2010	
14	Industries of other non-metallic mineral products	2006–2010	
15	Metallurgy and metal products manufacturing	2006–2010	
16	Machine building, electronics and optics industries	2006–2010	
17	Manufacture of transport equipment	2006–2010	
18	Miscellaneous manufacturing industries	2006–2010	
19	Water collection, purification and distribution	2008–2013	
20	Power and gas production and distribution	2008–2013	http://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t26/p067/p02/agua07-10&file=pcaxis&L=0 accessed on 24 March 2023
21	Construction	2008–2013	
22	Wastewater and sewerage sanitation activities	2008–2013	
Tertiary sector			
23	Hotels	2001–2015	https://ine.es/dynt3/inebase/es/index.htm?padre=238&dh=1
24	Restaurants	2008–2013	http://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t26/p067/p02/agua07-10&file=pcaxis&L=0 accessed on 24 March 2023
25	Other economic activities (services)	2008–2013	http://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t26/p067/p02/agua07-10&file=pcaxis&L=0 accessed on 24 March 2023
26	Water supply	2000–2014	http://www.ine.es/jaxi/Tabla.htm?path=/t26/p069/p03/serie/l0/&file=01001.px&L=0 accessed on 24 March 2023

Table A1. *Cont.*

SPAIN		
Economic Sector	**Period**	**Source**
FRANCE		
Economic Sector	**Period**	**Source**
Primary sector		
Surface water used for agriculture	2008–2013	Producteurs: MEEM (CGDD/SOeS), Agences de l'Eau. Source: Données Agences de l'eau, estimations SOeS. accessed on 27 March 2023
Secondary sector		
Surface water used for industry		
Tertiary sector		
Surface water used for domestic purposes		
PORTUGAL		
Economic Sector	**Period**	**Source**
Primary sector		
Agriculture and livestock	2006–2016	https://www.ine.pt/bddXplorer/htdocs/minfo.jsp?var_cd=0001868 accessed on 28 March 2023
Secondary sector		
Industrial		
Tertiary sector		
Commercial and services		
Domestic		

Table A2. Gross value added and employment data sources in SUDOE for primary, secondary, and tertiary economic sectors and domestic uses.

At Regional (NUTS 2) Level		
	Period	**Source**
Gross value added NACE constant prices	2000–2016	https://data.europa.eu/data/datasets/pksefp7fasxtmhta9nkozq?locale=en accessed on 2 April 2023
Average hours worked per employee, by working time—LCS survey		https://ec.europa.eu/eurostat/cache/metadata/en/lcs_r2_esms.htm accessed on 2 April 2023
Population statistics at regional level		https://ec.europa.eu/eurostat/databrowser/view/demo_r_d2jan/default/table?lang=en&category=reg.reg_dem.reg_dempoar accessed on 2 April 2023

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