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AN INPUT-OUTPUT HYDRO-ECONOMIC MODEL TO ASSESS THE ECONOMIC PRESSURE ON WATER RESOURCES IN TUSCANY

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Abstract

In this work, an input-output hydro-economic model based on the Guan and Hubacek (2008) methodology is applied for the Tuscany region in Italy. The model integrates the input-output table (for the year 2017) of the regional economy developed by IRPET with a satellite account, expressed in volume (cubic meters of water), accounting for the flows of water resources between the hydrological system and the economy.

Two innovations are incorporated in the model: i) the reclassification of withdrawals and restitutions of water by demanding sector and ii) the creation of an indicator of pressure on water resources based on an analysis of the feasible water supply. The model is built on the basis of economic and hydrological data generated by the different national and regional institutions, also using specific methodologies that are described in this work. The developed model provides estimates of the net water demand generated by 56 economic sectors and by the ecosystem requirements, and allows to compare the net demands by extracting and demanding sectors. The indicator of economic pressure on the total water resource, groundwater and surface water supports a better understanding of the linkages existing between the economic activities and the regional hydrological system.

Key words: Input-output models, water resources, hydrology, Tuscany

JEL Classification: C67, Q25, Q50

Summary

1 INTRODUCTION

This paper presents a multisectoral model of the Tuscan economy to support monitoring and forecasting of the use and treatment of water resources in the coming years, according to the Tuscan Water Protection Plan (PTA) as provided for by Regional Council Resolution No. 11 of 10 January 2017.

The hydro-economic model that we develop integrates the input-output table (for the year 2017) of the regional economy developed by IRPET with a satellite account, expressed in volume (cubic meters of water), related to the flows of water resources generated in the hydrological system by production activities.

The Tuscany Region and other agencies involved in various ways in the management and control of regional water resources made available a wide set of information sources used to reconstruct the following components of the regional hydrological balance:

- The withdrawals of water resources (classified by water body) generated by the various production activities existing in Tuscany (classified as "industries" according to the NACE classification)

- The water restitutions to the hydrological system made by each industry classified by water body and by levels of water quality according to the quality thresholds allowed by the different uses (e.g., civil, industrial).

The interaction between water restitutions of different quality levels to different bodies of water and the net availability of water complying with minimum quality standards for different forms of use is also modeled.

Based on the collected information, a hydro-economic model of the Tuscan economy has been developed, building on the approach proposed in Guan and Hubacek, (2008) and developing the model to better represent the characteristics of the Tuscan economic and hydrological system.

The paper is organized as follows. In the following section the structure of the input-output model extended to water resources is presented. In Section 3 is presented an indicator of pressure on water resources built using the output of the model. Section 4 describes the data and methods used to implement the empirical model. Section 5 provides the results of the model for the reference year in terms of net water demand classified both by industry and by water body; based on the output of the model an assessment of the overall level of pressure on water resources in Tuscany is carried out. Final remarks and suggestions for future research are proposed in section 6.

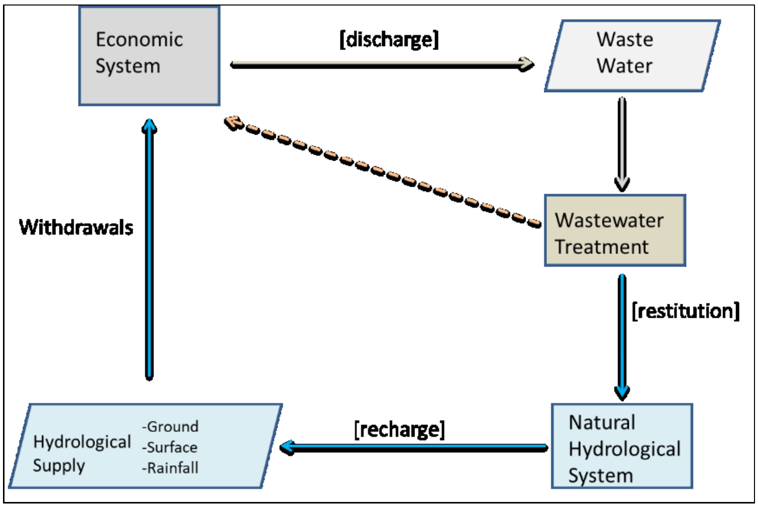
2 INPUT-OUTPUT HYDRO-ECONOMIC MODEL

2.1 The Guan and Hubacek (2008) input-output hydro-economic model

The hydro-economic scheme proposed by Guan and Hubacek (2008) models the relationship between the global regional hydrological balance (in terms of available and used resources) and the level of activation of the production system.

Figure 1 summarizes the main linkages between economic and natural hydrological system. On one side the production activities withdraw water from the water bodies composing the hydrological system. This extraction generates a pressure on the components of the hydrological system that is different depending on the nature of the economic activity. While agriculture is also able to use the natural supply of water from rainfall, other economic activities withdraw the water needed from surface and ground bodies, depending on the technology adopted and the geographical position of each establishment.

Figure 1
Water flows in the hydro-economic model



Source: Own elaboration

On the other side the economy interacts with the natural hydrological system also discharging residual water (net of water incorporated in products). This downstream flow represents a positive contribution to the hydrological balance (recharge of water body) but also affects the availability of the resource for other uses depending on the quality of discharged waters. While water restituted after treatment can be considered a positive inflow for the hydrological system, untreated wastewater discharged in the environment represents a further pressure on the hydrological resources that can be quantified as an additional requirement of clean water necessary to restore the quality equilibrium of the hydro system and unavailable for economic uses.

Following Guan and Hubacek (2008), the water balance can be summarized with the following simple equation:

Total water demand =

(+) Water extractions for domestic and productive uses
(-) Return of water to the hydrological system
(+) Unavailable water for qualitative balance of water bodies

Let A_d the (*n* x *n*) matrix of coefficients that represents the structure of intermediate consumptions per unit of output of production activities, calculated from the domestic flows input-output table. The total production of the *n* productive sectors can be calculated from the following equation:

$$x = (I - A_d)^{-1}y \tag{1}$$

where x is the vector of gross output of the industries, y is the vector of the final demand and I is the unit matrix. In the hydro-economic approach, the model is expanded to link the level of activation of each industry with exchange flows between production activities and the water bodies composing the hydrological system. Let:

f_i be the (*n* x 1) vector of the unit water withdrawal coefficients (m^3/€) of industries from the water body i.
r_i be the (n x 1) vector of the unit water restitution coefficients (m^3/€) of industries to the water body i.

Net extraction of water from the economic system of a given body of water is given by:

$$p_i = \left(\widehat{f_i} - \widehat{r_i}\right)(I - A_d)^{-1}y, \qquad i = 1, \dots, m \tag{2}$$

where the hat symbol indicates the diagonalization of the vector. By repeating the operation for the *m* bodies of water considered in the model it is possible to constitute the (*n* x *m*) matrix P representing the net demand of water of the *n* productive sectors from the *m* bodies of water. Equation (2) can also be used to simulate the impacts of changes in the vector of final demand on the pressures that the production system exerts on water resources.

Equation (2) only considers pressures from a quantitative point of view. However, the total net demand per body of water should be corrected to take into account the water required to guarantee the quality equilibrium in the water bodies.

The quality balance in the hydrological sector can be represented from the following equation:

$$h_i = \Sigma_k v_{ik} + e_i, \qquad i = 1, \dots m, k = 1, \dots m \tag{3}$$

where h_i is the amount of water with minimum quality characteristics "required" by the ecosystem in the water body, composed of natural losses (e_i) and the amount of water required to dilute contamination from the water body i to the water body j (v_{ik}). The term v_{ik} can be further broken down by indicating that:

$$v_{ik} = b_{ik} h_k \ or\ alternatively \ \ e_{ik} = \frac{v_{ik}}{h_k} \tag{4}$$

where b_{ik} (mc/mc) is a coefficient of exchange between water bodies representing the amount of water needed by the water body *i* to restore the qualitative equilibrium (minimum standard quality) for each cubic meter of water from the water body *j* (including natural losses during the dispersion process) needed to restore the balance in body *i*. By combining equations 3 and 4 we get:

$$h_i = \Sigma_k b_{ik} h_k + e_i \qquad i = 1, \dots m, k = 1, \dots m \tag{5}$$

that reordered and rewritten with matrix notation to consider all water bodies represented in the model becomes:

$$(I - B)h = e \tag{6}$$

Where h is the (*m* x 1) vector of uncontaminated water requirements by different bodies of water, including natural losses and "unavailable" water needed to restore the standard quality in the water bodies, e is the (*m* x 1) vector of natural water losses in the ecosystem, B is the (*m* x *m*) matrix of coefficients of exchange between bodies of water. By solving equation (6) we get:

$$h = (I - B)^{-1} e \tag{6}$$

This version of the model has not considered the relationships between the different bodies of water, limiting the quantification of internal of groundwater and surface water exchanges.

2.2 Reclassification of water flows by demanding sectors

The model presented in the previous section shows the linkages between economic activities and the direct withdrawals and restitutions of water for each economic sector and for each water source.

Let define z the vector of domestic production (internal flows) of industries

$$z \equiv (I - A_d)^{-1} y \tag{7}$$

It is possible to rewrite equation (2) based on (7),

$$p_i = (\hat{f}_i - \hat{r}_i) z, \qquad i = 1, \dots, m \tag{8}$$

Vector p_i represents the net use of water by each economic sector from the source i of water. However, coefficient in vectors f_i and r_i are different from zero only for production activities that actually withdraw and discharge water from/to water bodies. Despite all production activities require and discharge water (although in different extent), the withdrawals and the restitutions of water to different bodies of the hydrological system are actually carried out only by a limited number of industries (extracting sectors). For example, the largest part of service activities purchase water from the water service sector and restitute water throughout the sewage service sector. Referring to equation (8) would provide only a partial view of the interdependencies existing between the economic and the hydrological system.

It is of interest to know the use of water reclassified by *demanding* sector. This could be done adding to the total direct use of water of each sector, as represented by vectors f_i and r_i, the "implicit" demand of water from other sectors associated with the purchase of intermediate inputs; and subtracting the "implicit" sales of water to other sectors *via* the supply of intermediate inputs as well.

The vector of "implicit" water sales associated with the water source i is,

$$s_i = (\hat{f}_i - \hat{r}_i) A_d z \tag{9}$$

The vector of "implicit" water purchases associated with the water source i is,

$$c_i = \left(\widehat{f_i} - \widehat{r_i}\right) A_d{}' z \tag{10}$$

Thus, the reclassified water use vector (q_i) for the water source i can be written based on equations (8), (9) and (10).

$$q_i = p_i - s_i + c_i = \left(\widehat{f_i} - \widehat{r_i}\right)(z - A_d z + A_d{}' z) \tag{11}$$

Repeating this procedure for each of the *m* water sources, the (*n* x *m*) matrix Q is obtained, representing the net extractions from the *m* bodies of water reclassified by demanding sector.

Working only with the coefficients of withdrawals or restitutions, instead of the difference (net water use), it is possible to obtain reclassified withdrawals and reclassified restitutions of water, by economic sector and water source.

3 AN INDICATOR OF PRESSURE ON WATER RESOURCES

3.1 IPRI with natural supply

The indicator of pressure on water resources (IPRI) is defined as the ratio between the net demand for water and the supply of water.

$$IPRI = \frac{Water\ Net\ Demand}{Water\ Supply}$$

The hydro-economic model generates net demand results (withdrawals minus restitutions) for groundwater, surface waters and the hydrological cycle (rainfall). Interesting for the purposes of this study is the assessment of the IPRI for all water and separately for surface and groundwater.

To determine the water supply it is important to know the components of the hydrological balance, which correspond to precipitation (P), evapotranspiration (E), groundwater recharge (I) and runoff (R). These are physically related as follows:

$$P = E + I + R$$

The annual natural supply of water (S^{nat}) corresponds to the sum of the recharge of the aquifers (I), the runoff (R) and that part of the precipitation that goes directly to agriculture $(\widehat{C_{A\,C\iota}})$.

$$S^{nat} = I + R + \widehat{C_{A\,C\iota}}$$

As a consequence, the IPRI with natural supply can be defined as

$$IPRI^{nat} = \frac{Water\ Net\ Demand}{I + R + \widehat{C_{A\,C\iota}}}$$

3.2 IPRI with feasible supply

A change in the supply estimate affects the pressure indicator on water resources (IPRI), which tends to be higher, on average, when considering the Feasible Supply rather than the total Natural Supply.

$$IPRI = \frac{Net\ Demand}{Feasible\ Supply} > \frac{Net\ Demand}{Natural\ Supply}$$

The most relevant aspects that define the feasible supply are described below, for the surface water and groundwater, identifying technical, institutional and environmental limitations to water supply, as well as proposing a definition of feasible supply.

3.2.1 Surface water

The technical, institutional, and environmental limitations that characterizes the feasible supply for surface water are:

- Although rivers are renewed year after year, it is clear that not all the runoff of water can be used for economic purposes
- In the years of high flow, the possibility to capture and accumulate water (hydraulic works) is limited.
- In the years of high flow, it could not be possible to extract all the water because the concessions do not allow it.
- It is not environmentally possible to extract all available water as there must be a minimum "ecological" flow. This sustainability condition for surface water bodies is not incorporated into the model. The Feasible Supply must consider that it is possible to withdraw water up to a certain maximum quantity.

The proposed definition of feasible supply of surface water is the following:

- The maximum amount of surface water extraction is defined by the sum of the maximum withdrawals allowed by current concessions.
- The assumption we make here is that the concessions have been efficiently awarded, taking into account all technical and hydrological aspects.
- The surface water supply is considered to be limited by a minimum "ecological" flow, as a constraint to environmental sustainability.
- The Maximum concessions levy is defined as $M\bar{R}$, where M is a factor not necessarily less than 1 and $\bar{R}$ is the average annual runoff.
- The minimum Ecological flow is defined as $E\bar{R}$, where $E \in (0,1)$
- When R_t is less than $M\bar{R} + E\bar{R}$ and greater than $E\bar{R}$, the feasible runoff value (R_t^{fatt}) is equal to R_t
- When R_t is greater than $M\bar{R} + E\bar{R}$, the feasible runoff value is $M\bar{R}$
- For the case in which $R_t - E\bar{R} < 0$, there will be no availability of surface water for economic uses.
- As a result, the feasible annual average runoff will be strictly lower than the $\bar{R}$ value.

Summing up the value of R_t^{fatt} is:

$$R_t^{fatt} = \left\{ \begin{array}{cc} R_t - E\bar{R} & if\ \ E\bar{R} < R_t < M\bar{R} + E\bar{R} \\ M\bar{R} & if\ \ R_t > M\bar{R} + E\bar{R} \\ 0 & if\ R_t < E\bar{R} \end{array} \right\}$$

3.2.2 Groundwater

The technical, institutional, and environmental limitations that characterizes the feasible supply of groundwater are:

- Groundwater corresponds to a stock that varies according to the annual recharge. Consequently, the extraction available annually depends more on the average annual top-up than on the top-up of the year.
- Unlike surface water, if the recharge in a year is low, it is still possible to extract a larger quantity (reservoir effect).
- When the cooldown is high, there are technical limitations to extraction.
- The feasible recharge can be equal to the average recharge (which ensures sustainability, i.e. a non-decreasing groundwater stock), which is why there is no limitation on the part of the concessions (which are assumed to be equal to or lower than the average annual recharge)

The proposed definition of the feasible supply of groundwater is the following:

- The sustainable extraction is assumed equal to the average recharge. However, there are some variations that depend on the stock of the resource and the amount of water that infiltrates during the year.
- For the scenario in which there is no over-exploitation of the aquifers, that is, there are no large variations in the stock, it makes sense to assume that sustainable extraction will be around the average recharge, that is, it will be a little higher for a rainy year and a little less for a dry year.
- In fact, in general, groundwater concessions are awarded for a slightly higher value than sustainable recharge, since there are years in which it is not possible to extract the average recharge (technical limitations, especially for small users) and other years in that it is possible to extract more than the average recharge.
- We consider the sum of the groundwater concessions (D) to define the feasible upper supply limit. In this way, the difference between the sum of the concessions and the average annual recharge $(D - \bar{I})$, defines the share B by which the average recharge can be increased to build the feasible recharge $(B = \frac{D-\bar{I}}{\bar{I}})$ where $B \in (0,1)$ and $\bar{I}$ is the average annual recharge.
- It is assumed that the feasible groundwater supply (that can be drawn in one year) will be in the range $[\bar{I}(1-B), \bar{I}(1+B)]$.
- When I_t is lower than $\bar{I}(1-B)$, the feasible supply value (I_t^{fatt}) is $\bar{I}(1-B)$
- When I_t is greater than $\bar{I}(1+B)$, the feasible supply value is $\bar{I}(1+B)$
- When I_t is in the range$[\bar{I}(1-B), \bar{I}(1+B)]$, the feasible supply value is I_t
- Consequently, if the distribution of I is symmetrical, the feasible annual average supply will be equal to the value $\bar{I}$

Summing up the value of I_t^{fatt} is:

$$I_t^{fatt} = \left\{ \begin{array}{cc} \bar{I}(1-B) & if\ \ I_t < \ \bar{I}(1-B) \\ \bar{I}(1+B) & if\ \ I_t > \bar{I}(1+B) \\ I_t & if\ \ I \in [\bar{I}(1-B), \bar{I}(1+B)] \end{array} \right\}$$

3.2.3 Definition of the IPRI based on feasible supply

Based on what has been developed in the previous sections, it is possible to calculate the IPRI for the total resource ($IPRI_t^{RT\_fatt}$), for surface waters only ($IPRI_t^{Sup\_fatt}$) and for groundwater ($IPRI_t^{Sott\_fatt}$), on an annual scale.

We consider:

DI_t: Annual groundwater demand, year t
DR_t: Annual surface water demand, year t

Therefore, the pressure indicator on the water resource (IPRI) considering the Feasible Supply is expressed as:

$$IPRI_t^{RT\_fatt} = \frac{DI_t + DR_t}{R_t^{fatt} + I_t^{fatt}}$$

$$IPRI_t^{Sup\_fatt} = \frac{DR_t}{R_t^{fatt}}$$

$$IPRI_t^{Sott\_fatt} = \frac{DI_t}{I_t^{fatt}}$$

4 DATA FOR THE CONSTRUCTION OF THE MODEL

4.1 Breakdown of the agricultural branch in the input-output table of the Tuscany region.

Agriculture is an industry that, in some of its sectors, makes intensive use of water resources for both crop irrigation and livestock rearing. In the regional table provided by the Regional Institute of Economic Planning for Tuscany (IRPET), agriculture is represented as a single branch, hiding under an average figure the diversification of agricultural production activities that characterize the sector at the regional level. We carried out a disaggregation of agriculture in the table aims to have a better representation of production activities making the model suitable to provide results suitable to support the management of water policy at the regional level.

The breakdown of any of the industry represented in an input-output table should take into account the accounting conventions adopted in building the production accounts of the different sectors. Specifically, each industry represents an aggregation of production units classified according to a similarity criterion of the production process. The basic criterion concerns the nature of the product: the production activities of a single product producing the same good have to be added into a single industry. In the case of agriculture, most production units are typically multi-product, performing a multiplicity of production processes (different crops and/or livestock holdings); therefore, when the disaggregation into sub-sectors ask for a suitable, a classification criterion of production activities.

According to accounting conventions, multi-product production units should be allocated to different industries depending on the production that generates the largest value-added quota. In principle, this criterion would require the availability of microeconomic information with a level of detail that would allow the intermediate consumption of the production units to be subdivided among the different production processes carried out by production units. If this information is barely available to other sectors, it is even more difficult to find it in the case of agriculture, where small units predominate and are mostly family-owned enterprises. In the breakdown, therefore, the accounting criterion must necessarily be approximated using alternative and practicable forms of classification.

One possible solution is to disaggregate the agriculture industry by distinguishing subgroups of production units classified by Farm Type (FT). The FT is a farm classification criterion defined at European Union level and used in economic analyses to support sector policies (Common Agricultural Policy). The FT classification is also applied by ISTAT in carrying out the general census of agriculture and the periodic surveys on agricultural holdings. The current classification by FT is defined by Regulation 1242/2008 which identifies 8 general FTs (farms specially specialized respectively in arable crops, horticulture, permanent crops, herbivorous breeding, granivore breeding, polyculture farms, polyculture farms, mixed crop breeding farms) which in turn can be disaggregated, according to a hierarchically organized nomenclature, into 21 main FT and 61 particular FT.

The FT is assigned to holdings using of structural data weighted on the basis of standard economic values estimated at the regional level. In particular, according to current regulations, the specialization of agricultural holdings is determined according to the contribution of each production process to the standard output. Standard output is calculated by multiplying the physical size of each production process by a standard unit value, estimated at the regional level. The FT's is the assigned taking into account a threshold system that normally follows a rule that we could define "of two-thirds": for example, farms where the standard output produced by annual crops (made on arable land) exceeds 2/3 of the total are considered "specialized in arable crops". Mixed FT are assigned when no production process reaches this prevalence quota. A similar mechanism is used to assign FT to lower levels of the hierarchy (for example, within arable crop farms to identify "cereal-specialized" farms).

For the construction of the model, we disaggregated agriculture into 8 subsectors corresponding to the 8 general FT. The adoption of the FT as a criterion of disaggregation of agriculture has a number of advantages:

- The classification of the FT, although not identical, is substantially consistent with the reference accounting conventions for the classification of economic activities (NACE classification).

- The main sources of statistical information, both primary (microeconomic data) and secondary (official statistics published by ISTAT) on Italian agriculture use this method of disaggregation of the sector.

- The distribution of farms by FT is available for Tuscany at the municipal level (2010 Agricultural Census data). This makes it possible to relate water extractions for agricultural uses detected/estimated by the region at the subregional level based on the composition of agricultural production, with the specific composition by FT, thus allowing to estimate at the regional level average water use coefficients referred to each individual FT

The statistical information available to disaggregate the agriculture on the basis of FTs consists essentially of two surveys: the survey on the Economic Performances of Agricultural Holdings (REA, carried out by ISTAT). The REA survey provides a detailed breakdown of the production costs of the farms surveyed for the construction of the national economic accounts of the agricultural sector, as well as the classification of the holdings observed by the FT. A second source of information is a sample of farms surveyed by CREA under the European Farm Accounting Data Network (FADN). The FADN Public

Database (http://ec.europa.eu/agriculture/rica/index.cfm) provides data on the composition of farm production costs at the national and regional levels and with a breakdown by FT. In addition, through CREA it is possible to access the microeconomic information of the sample.

4.2 Water extraction coefficients for irrigation

The estimation of water extraction coefficients for irrigation uses was carried out in three steps:

a) estimates of the average potential irrigation needs of Tuscan agriculture
b) estimate of total irrigation intakes
c) attribution of intakes to the sub-sectors of Tuscan agriculture

4.2.1 Methodology for estimating irrigation needs

The estimation of irrigation needs has been first developed at the municipal level, using the irrigated areas detected by ISTAT with the 2010 Census by crop type. This, In fact, is the most detailed source of official information at the territorial level, although it is only updated every 10 years.

The municipal areas of the different irrigated crops surveyed by ISTAT in 2010 were aggregated by irrigation districts on the basis of geographical and climatic similarities. To each climatic area a unit irrigation need has been assigned, derived from bibliographic and research data, mainly related to experimental tests and irrigation consulting activities carried out in Tuscany.

Since most of the available data on irrigation needs relate mainly to the Val di Chiana, Val di Cornia and Grosseto areas, the determination of the irrigation needs of the other areas has been carried out by identifying specific conversion coefficients, derived from the comparison of the potential evapotranspiration (ETP) of the stations present in the individual areas with those of the reference zones.

Particular assumptions have been made on irrigation consumption with reference to specific productive activities, such as in the case of nursery production, or areas specialized in particular crops (such as tobacco cultivation in Val di Chiana and Valtiberina).

4.2.2 Estimation of total irrigation water intakes

The estimates of irrigation needs described above provides average theoretical irrigation consumption data by municipality and climatic area and refer to the agricultural areas surveyed in 2010. For the purpose of estimating irrigation extractions it has been considered an average increase of 30% compared to estimated needs. This correction take into account some elements of variability, which can significantly affect the volumes actually used for irrigation:

a) the weather of the year and in particular during the irrigation season
b) the average level of efficiency of irrigation systems.
c) The actual extent of crops, which varies over the years depending on crop rotation and choices made by the farmer.

It should be noted for item (c) that, based on ISTAT surveys, in the last 20 years in Tuscany the trend of irrigation has been downward: the areas actually irrigated have decreased by about 30% in the period 2000 to 2010 alone. Based on ISTAT's inter-census surveys and the information collected by regional extension services, it is assumed that in recent years the overall irrigated areas remained substantially stable, but with a redistribution among different types of crops, due to the variability of crop systems. The availability of water is, in fact, a limiting factor for the increase in irrigated crops.

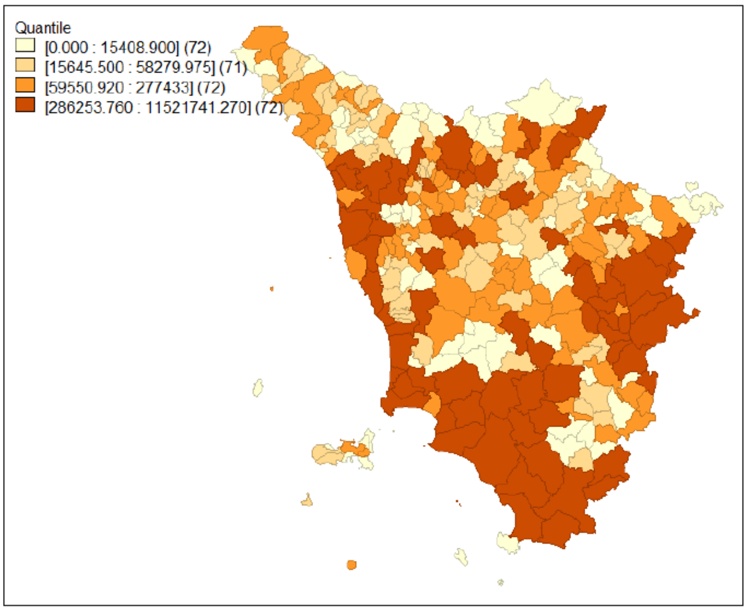
Table 1. Withdrawals for irrigation in Tuscany by climatic area (m^3)

Climatic Areas	**Withdrawals of water for irrigation *(m^3)***
5. VAL DI CHIANA	22 452 294
4. OMBRONE PISTOIESE	14 209 940
1. BASSA MAREMMA	9 194 618
2. BASSO OMBRONE	12 310 133
6. VALDICORNIA	7 917 420
8. VERSILIA	2 523 459
9. OMBRONE SUPERIORE DESTRO E SINISTRO	5 363 629
3. COSTA LIVORNESE	4 761 519
12. PIANURA DI FOLLONICA E COLLINE MAREMMANE	6 288 670
11. BASSO SERCHIO E PADULE DI BIENTINA	2 476 071
17. VALDINIEVOLE	2 139 138
7. VALTIBERINA	4 118 377
16. PIANURA PISANA	2 537 510
23. VALDARNO	1 835 634
18. VAL DI PAGLIA	552 857
25. BASSA VALDERA E VALDEGOLA	1 371 404
20. AREA FIORENTINA	1 219 484
27. VAL DI SIEVE	2 753 497
21. CASENTINO	867 830
15. LUNIGIANA	657 540
24. VALDELSA	1 326 804
13. GARFAGNANA	634 528
22. COLLINE DEL FIORA	736 123
10. ALTA VAL DI CECINA E ALTA VALDERA	569 509
14. ARCIPELAGO TOSCANO	206 705
19. ALTO RENO	41 125
26. VAL DI BISENZIO	29 176
TOTAL	**109 094 993**

Source. Own elaboration

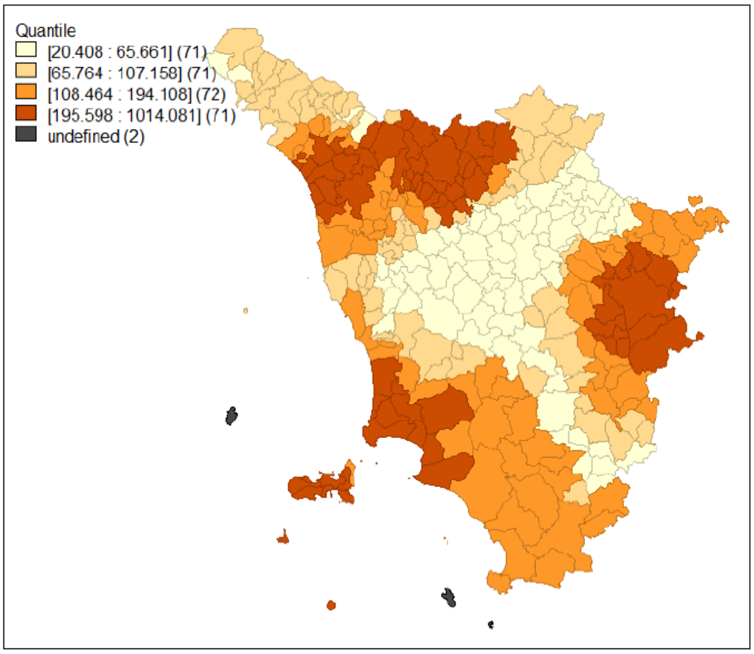
Table 1 presents a summary of the estimated annual average withdrawal by homogeneous territorial area. Figure 2 shows the geographic distribution (at the municipal level) of withdrawals expressed in absolute value.

Figure 2. Average annual water withdrawals for irrigation purposes in the municipalities (m^3)



Source. Own elaboration

Figure 3. Intensity of irrigation withdrawals in Tuscany (m^3/ha)



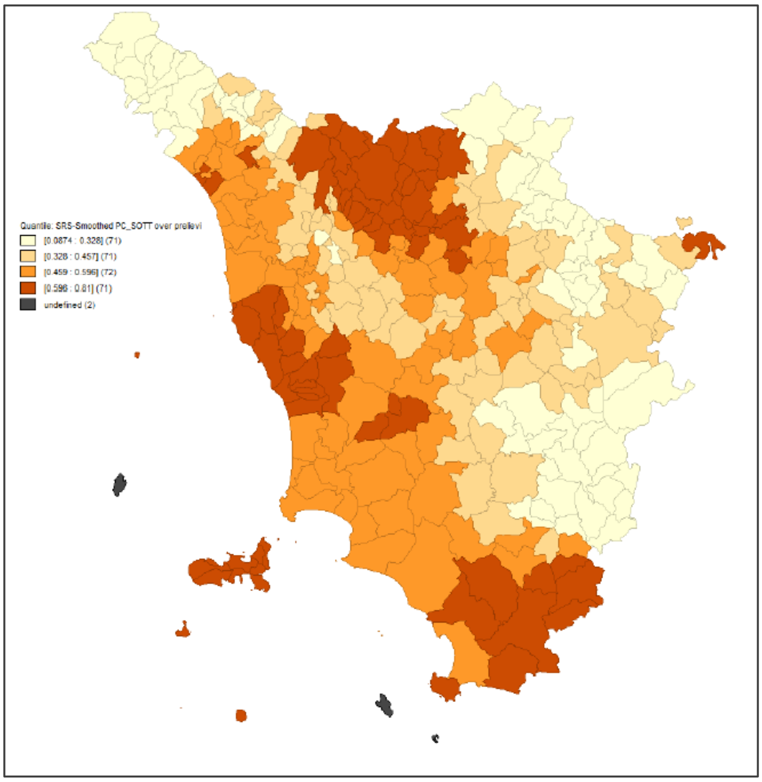
Source. Own elaboration

It is also interesting to represent territorial differentiations of the intensity of irrigation water use. Figure 3 shows the average consumption of irrigation water per hectare of agricultural area. Values at the municipal level have been corrected according to a spatial "smoothing" technique that averages gross values at the municipal level and the values of the nearest municipalities weighted by distance. The adjustment allows highlighting the spatial patterns existing in the regional territory.

The extractions at the municipal level have been divided between underground sources of supply (wells and springs) and surface sources of supply (reservoirs, lakes, rivers and streams) from the information available in the 2010 General Agricultural Census at the municipal level. Together, the two sources of supply are substantially balanced at the regional level, representing respectively 49.6% and 50.4% of total withdrawals.

Figure 4 represents the share of supply of underground sources in municipalities and allows to evaluate the territorial distribution of water extraction modalities for irrigation.

Figure 4. Impact of underground sources on water supply for irrigation



Source. Own elaboration

4.3 Allocation of irrigation intakes to the subsectors of Tuscany agriculture

A particular preparation of the data of the census of Tuscan agriculture has made it possible to map the withdrawals at the municipal level to the withdrawals that can be attributed to the subsectors of regional agriculture. This has been done reclassifying the hectares of different crops (on which were based the estimates of irrigation intakes) according to the FT of the holding in which they have been carried out.

The following table summarizes the average annual withdrawals from each subsector of regional agriculture. The third column shows the value of the gross output of subsectors, as shown in the input-output table of Tuscan agriculture. The ratio between the two values represents the average water extraction coefficient for irrigation of regional agriculture subsector to be included into the hydro-economic model of the regional economy.

In agriculture subsectors, the structure of irrigation intakes is biased towards underground sources of supply for farms specializing in horticulture (68.3% of supply); on the contrary, farms specialized in the rearing of granivores (which, however, account for less than 1% of irrigation intakes) are mainly supplied from surface sources (76.8%).

Table 2. Average annual irrigation withdrawals and extraction coefficients of Tuscan agricultural subsectors

Farm Type	Irrigation withdrawals (m^3)	Extraction coefficients (m^3/€)
Arable land	37 123 126	0.097
Horticulture	10 143 522	0.013
Permanent crops	33 727 005	0.024
Grazing livestock	9 960 097	0.537
Granivores	964 035	4.618
Mixed crops farms	11 587 147	0.093
Mixed livestock farms	435 480	0.167
Mixed crops-livestock farms	5 154 580	0.179
Total	109 094 993	0.078

Source. Own elaboration

4.4 Water extraction coefficients for livestock breeding

The estimation of water use coefficients for livestock production activities was based on the coefficients found in the technical literature and referred to the needs of water per head of livestock per day. Table 3 shows the coefficients used in this first version of the model for each type of livestock.

Table 3. Water consumption coefficients for livestock breeding

Livestock type	l/die
Dairy cattle	150.00
Other cattles	40.00
Sheeps and goats	3.00
Pigs	70.00
Poultry	0.17

Source. Own elaboration

Total water consumptions for livestock were calculated by multiplying unit coefficients by the number of livestock heads raised in Tuscany collected by the sampling survey on agricultural structure and production in 2013. The estimated total consumption was then distributed among the different FTs based on adult livestock units according to data from the FADN[1].

As shown in Table 4, the estimated total water consumption for breeding is around 7.3 Mm^3, concentrated for the most part, as is obvious given the structure of Tuscan agriculture in farms specializing in herbivore breeding. In the table, the total is also divided by supply source.

Approximately 1 $Mm^3$is supplied by public drinking water distribution networks[2], while the rest comes from self-supply sources disaggregated according to the same percentages used in water disaggregation for irrigation use.

The last column shows the extraction coefficients per Euro of gross output that have been used in the model. As can be seen, they assume a value not negligible only on farms with specialization in breeding.

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[1] Livestock Units are a standardized measure of the size of the holdings of the different domestic species obtained by weighing the number of animals raised with special coefficients. The coefficients defined by EC Regulation 1200/2009 have been adopted in this analysis.

[2] Data provided by the Tuscany region.

Table 4. Average annual water withdrawals for livestock breeding and extraction coefficients of Tuscan agricultural subsectors

Farm Types	Irrigation withdrawals (m^3)	Extraction coefficients (m^3/€)
Arable land	4 756	0.000
Horticulture	0	0.000
Permanent crops	115 642	0.000
Grazing livestock	5 859 260	0.047
Granivores	521 770	0.043
Mixed crops farms	63 057	0.000
Mixed livestock farms	153 894	0.008
Mixed crops-livestock farms	591 841	0.008
Total	7 310 220	0.002

Source. Own elaboration

4.5 Water extraction coefficients for other industries

Water supply industry

In the input output table of Tuscany is present the branch related to the activity of "Drinking water supply" which in the year considered produced a gross production equal to 1,035.80 M€. To obtain a withdrawal coefficient, the data provided by the Tuscany Region, drawn from the annual budgets of drinking water supply networks and relating to the quantities of water supplied and the corresponding turnover, have been used. Considering it acceptable, in the case of the supply of drinking water, the assimilation of turnover to gross output (which is substantially equivalent to considering the stocks of water held by the networks between the beginning and the end of the year) we proceed to calculate the average value of the withdrawal coefficient. The value is approximately 0.48 m^3/€ of gross output. This extraction coefficient has been divided between the bodies of groundwater (0.34 m^3/€) and the bodies of surface water (0.14 m^3 /€) using data from the water census data published in the Istat Datawarehouse with reference to year 2015 (http://dati.istat.it/Index.aspx?QueryId=20061).

In the absence of specific information at the regional level, water extraction coefficients for other productive activities have been derived from data for Italy contained in the report on "Water Use and Quality in Italy", published by ISTAT in 2019 (https://www.istat.it/it/archivio/234904). In section 2.2 (p. 67 and below) the report presents an estimate of water extractions and an estimate of the value of production sold for different manufacturing activities classified according to NACE rev2. The estimate is based on microeconomic data collected with the annual Prodcom survey on manufacturing activities. The coefficient used in the model are provided in Table 5. It should be noted that the coefficients obtained from the Istat report should be considered only as an approximation of the corrected withdrawal coefficients, since they are related the value of the production *sold*, without taking into account, changes in stocks, which in some sectors may be relevant.

In addition, Istat data do not provide information on water extractions from electricity production activities. In this case, the coefficient was obtained from the Italian data contained in the Exiobase database (https://www.exiobase.eu/).

Exiobase is a global multi-regional system of input-output-hybrid tables, i.e. extended to environmental components. It has been developed for research purposes by harmonizing existing input-output tables for several countries, linking them with tables of trade flows between countries and adding information and estimates on emissions and resource use from different productive sectors.

The sectors represented in Table 5 are those that, according to the Exiobase database, directly apply water withdrawals from water bodies for production or consumption purposes (extracting sectors). We hypothesized that water used in all other productive sectors is purchased of water from the water supply sector.

Table 5. Extractions coefficients for non-agricultural production activities

Industries	**Extraction coefficients (m^3/€)**
Mining and quarrying	0.0230
Food products and benerages	0.0037
Textiles	0.0207
wearing apparel	0.0033
Leather and related products	0.0020
Footwear	0.0020
Wood and wood products except furniture	0.0059
Paper, printing and recorded media	0.0074
Chemical and chemical products	0.0235
Pharmaceutical products	0.0142
Rubber and plastic products	0.0124
Other non-metallic products	0.0112
Manufacture of basic metals	0.0027
Metal products	0.0074
Computer, electronic and optical products	0.0024
Electrical equipment	0.0039
Machinery and equipment n.e.c.	0.0025
Motor vehicles and other transportation means	0.0014
Furniture	0.0005
Jewellery, bijouterie and related products	0.0067
Other manufacturing	0.0067
Repair and installation of machinery and equipment	0.0005
Electricity power generation transmission and distribution	0.0859

Source. Own elaboration

The distribution of water extraction coefficients for production activities between groundwater and surface water was based on reasonable ad hoc assumptions. In general, it was assumed that the source of direct water supply for production activities were surface water bodies. For some industries, supply was divided between surface and groundwater based on the breakdown of sources for civilian use resulting from the 2015 ISTAT Water Census.

4.6 Water discharge coefficients

The quantification of the restitution of water to the hydrological system by the productive sectors, in the absence of specific data, has necessarily been carried out from a series of hypotheses, using indirect information.

With regard to agriculture, three restitution flows, net of water incorporated into the products (the so-called "green" consumption) can be hypothesized: water losses during irrigation by evaporation, soil infiltration of water not used by plants, and the return of wastewater from livestock activities. In terms of infiltration losses, they are assumed equivalent to 30% of the water distributed to crops, in line with the estimate of irrigation needs presented above, in which the water needs of the crops (potential evapotranspiration) have been increased by 30% to take into account inefficiencies and waste in the distribution of water. As for the yields of the hydrological cycle for (effective) evapotranspiration, they have been calculated, from Exiobase coefficients and other technical data, applying a coefficient of 4% on natural water supply to crops. Also, in the case of livestock breeding, a technical coefficient of 13% of the water used by livestock was applied to quantify the wastewater discharge

An important component of the sector's restitutions to water bodies is that of losses in the water distribution network for civilian uses. It is apparent from the water census data carried out by Istat for 2015 that the actual water losses in the distribution were in Tuscany equal to 41% of the water inflows into the pipelines. It has been assumed that all distribution losses in water networks flow into groundwater.

In the Tuscan cross-sectoral table, water purification activities are also represented separately. In estimating the flow rates, in accordance with the results of the ISTAT Water Census, it has been assumed that the wastewater treatment activities of the productive activities were partly carried out by collective treatment plants and partly by treatment plants managed by the same productive activities.

Table 6. Unit coefficients of water return to water bodies by production sector

Industries	Surface water (m^3/€)	Ground water (m^3/€)	Natural losses (m^3/€)
Arable land	0.0238	0.0000	0.0355
Horticulture	0.0084	0.0000	0.0355
Permanent crops	0.0040	0.0000	0.0355
Grazing livestock	0.0234	0.0000	0.0355
Granivores	0.0225	0.0000	0.0355
Mixed crops farms	0.0095	0.0000	0.0355
Mixed livestock farms	0.0057	0.0000	0.0355
Mixed crops-livestock farms	0.0176	0.0000	0.0355
Mining and quarrying	0.0230	0.0000	0.0000
Food products and benerages	0.0000	0.0009	0.0000
Textiles	0.0000	0.0050	0.0002
Wearing apparel	0.0000	0.0008	0.0000
Leather and related products	0.0000	0.0005	0.0000
Footwear	0.0000	0.0005	0.0000
Wood and wood products except furniture	0.0000	0.0014	0.0001
Paper, printing and recorded media	0.0000	0.0017	0.0001
Chemical and chemical products	0.0000	0.0057	0.0002
Pharmaceutical products	0.0000	0.0035	0.0001
Rubber and plastic products	0.0000	0.0030	0.0001
Other non-metallic products	0.0000	0.0027	0.0001
Manufacture of basic metals	0.0000	0.0006	0.0000
Metal products	0.0000	0.0018	0.0001
Computer, electronic and optical products	0.0000	0.0006	0.0000
Electrical equipment	0.0000	0.0010	0.0000
Machinery and equipment n.e.c.	0.0000	0.0006	0.0000
Motor vehicles and other transportation means	0.0000	0.0002	0.0000
Furniture	0.0000	0.0001	0.0000
Jewellery, bijouterie and related products	0.0000	0.0016	0.0001
Other manufacturing	0.0000	0.0016	0.0001
Repair and installation of machinery and equipment	0.0000	0.0001	0.0000
Electricity power generation transmission and distribution	0.0000	0.0244	0.0009
Water supply	0.2160	0.0000	0.0000
Sewerage	0.0000	4.0346	0.1463

Source. Own elaboration

According to Istat data, industrial wastewater treated at treatment plants was about 304 Mm^{3}in 2015, equivalent to about 26% of total wastewater. To them we must add about 129 Mm^3 of wastewater produced by the production sectors not treated in collective treatment plants and estimated from coefficients obtained from the Exiobase database. Of this component it has been assumed that only 80% was purified by treated by activities before being reintroduced into the bodies of water. All values have been transformed into coefficients of return to the bodies of water expressed in m^3/€ of gross output. Finally, we assumed that that all productive activities reintroduce their wastewater into surface water bodies and that the discharge causes an evaporation loss equal to 3.5% of the volumes introduced. Table 6 shows the coefficients of return to the bodies of water used in model construction.

4.7 Flows within the hydrological system

The hydro-economic model also allows to quantify the water needed to guarantee a minimum level of water quality used for different purposes. In the Tuscan hydrological system, water treatment plants largely ensure that water reintroduced into water bodies after use in production and final consumption comply with standard qualitative levels compatible with their immediate reuse. Although the treatment is carried out on a large part of the water returned to the water bodies both from collective civil sewerage systems and from productive activities, it is reasonable to assume that a part of the wastewater reaches the hydrological system without the minimum qualitative characteristics for use, both for irregular discharges and due to deficiencies in the treatment infrastructures.

Following the approach proposed by Guan and Hubacek (2008) the reintroduction of water with a polluting load above the limits that allow its use is represented in the model as the cause of an additional demand for water equal to the volume of water with adequate quality that would theoretically be necessary to restore in the bodies of water an average quality compatible with use. It is a water that we could define as "unavailable" because it is necessary to ensure the qualitative rebalancing of the bodies of water.

To include this type of indirect demand in the model, it was necessary to calculate the average diluting coefficients expressed in terms of cubic meters of minimum quality water present in the bodies of water for each cubic meter of non-depurated water returned to the bodies of water by production activities. The calculation of the coefficients was carried out using simplified hydrological models, respectively for groundwater and surface water, proposed by Guan and Hubacek in their study on China (2008). The models were applied taking into account the previously estimated untreated wastewater volumes and assuming some hypotheses about the dilution process. In particular, it was assumed that:

a. The average water availability per equivalent inhabitant was 300 l/day
b. Not depurated water reintroduced into the bodies of water had an average polluting load of 300 DBO5
c. The dilution process in the water bodies brought the polluting load to an average value of 25 DBO5

4.8 Hydrological Balance and natural supply

In section 3.1 the variables of the hydrological cycle have been listed: precipitation(P), evapotranspiration (E), groundwater recharge (I) and runoff (R).

The Italian Institute of Statistics (ISTAT, 2021) provides information for each of these random variables in the period 2001-2010 in the Tuscany region (Table 7)

Table 7. Hydrological cycle components for Tuscany (2001-2010)

Year	Precipitation [P] (Mm^3)	Evapotranspiration [E] (Mm^3)	Groundwater recharge [I] (Mm^3)	Runoff [R] (Mm^3)
2001	16,398	10,070	2,606	3,551
2002	22,056	13,639	4,548	3,112
2003	16,923	9,655	3,742	3,195
2004	21,868	11,007	5,772	5,489
2005	19,880	10,922	4,571	4,704
2006	15,819	10,317	2,343	3,438
2007	14,027	10,616	1,979	1,704
2008	22,324	11,361	5,634	4,735
2009	21,119	10,750	5,336	4,356
2010	27,161	12,278	6,830	8,124

Source. Own elaboration based on ISTAT (2021)

Given the low length of the records (10 years), the time series for Tuscany is extended based on the series referring of the Northern Apennines District (Autorità di distretto dell'Appennino Settentrionale, 2021) for the period 1971-2010. In this way, it was possible to generate a 40-year record for each of the variables of the hydrological cycle.

The methodology for extending the series for Tuscany (Te Chow, 2010) corresponds to an adjustment of the Northern Apennines District data based on the common period, that is, the data for Tuscany in the missing period (1971-2000) will have the same structure than in the Northern Apennines District but will be different in level.

Let us consider the variables X and Y that represent each of the components of the hydrological cycle $(P,\ E,\ I,\ R)$ of the series for Tuscany and for the Northern Apennines District, respectively.

$\bar{X}^{CP}$: Mean variable for the Tuscany in the common period 2001-2010
X_t^{LP}: Variable year t for Tuscany in the period 1971-2000.
$\bar{Y}^{CP}$: Mean variable of the Northern Apennines District in the common period 2001-2010
Y_t^{LP}: Variable year t of the Northern Apennines District in the period 1971-2000.

Thus, the unknown variable X_t^{LP} is calculated for each year of the long period as:

$$X_t^{LP} = Y_t^{LP} \cdot \frac{\bar{X}^{CP}}{\bar{Y}^{CP}}$$

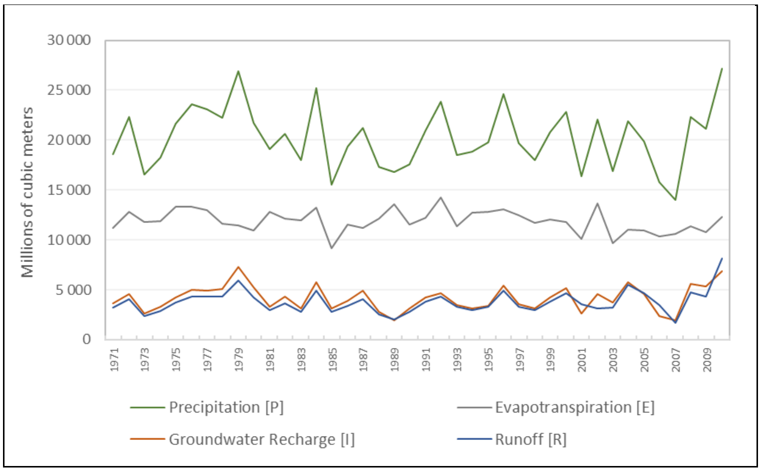
Table 8 shows the mean, standard deviation, coefficient of variation, and skewness for the components of the hydrological cycle in the period 1971-2010, for the Tuscany. Figure 5 shows the four components of the hydrological balance for Tuscany for the 1971-2010 period.

Table 8. Statistics of the extended hydrological series for Tuscany (1971-2010)

Year	Precipitation [P]	Evapotranspiration [E]	Groundwater recharge [I]	Runoff [R]
Mean (Mm^3)	20,269	11,892	4,155	3,803
S. Deviation (Mm^3)	3,084	1,129	1,258	1,156
C. Variation	15%	9%	30%	31%
Skewness	0.2	-0.2	0.4	1.3

Source. Own elaboration

Figure 5. Extended hydrological series for Tuscany (1971-2010)



Source. Own elaboration

With these data, the average natural supply of surface and groundwater can be constructed for the calculation of the IPRI. The total supply, as described in section 3.1, corresponds to the sum of surface water, groundwater and rainfall directly captured by the agriculture sector (a part of the variable P).

4.9 Feasible Supply

For the runoff, a value of $A = 64\%$ is considered. This value corresponds to the sum of all surface water concessions in Tuscany (2,473 Mcm), registered by the Regional Hydrological Service (SIR, 2021).

For the runoff, a value of $E = 20\%$ is considered. This means that surface water bodies will always have an average flow rate equivalent to 20% of the average annual flow. This is a rather conservative value, especially considering that it is a value on a regional scale (Moccia et al., 2020).

For the groundwater recharge, a value of $B = 13\%$ is considered. This value is calculated as $B = \frac{D - \bar{I}}{\bar{I}} = \frac{4{,}704 - 4{,}155}{4{,}155} = 13\%$. The maximum value of the concessions is 4704 Mcm while the average annual top-up is 4,155 Mcm (SIR, 2021). The choice of this value is also consistent with a high dependence on the stock and a low one with respect to the flow (even if not zero), the level of groundwater and fairly stable withdrawals (sustainability and concessions).

5 RESULTS

5.1 Water uses by extracting sectors

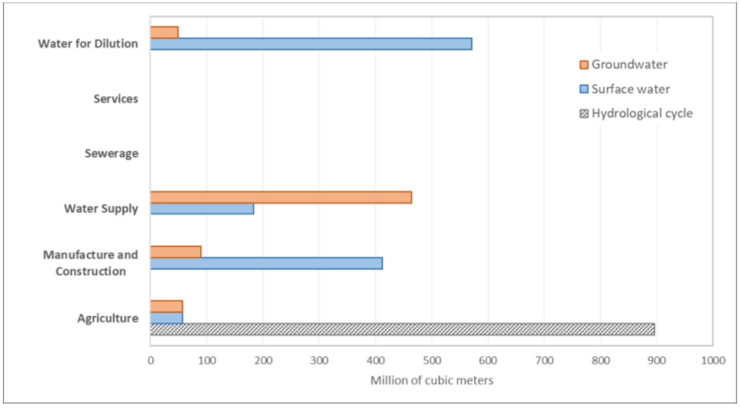
Table 9 shows the withdrawals, restitutions, and net demand for water for the five economic macro-sectors (extracting sectors)and the water requirements for dilution, for the non-reclassified case. Figures 6, 7 and 8 show the results by source of water.

Table 9. Withdrawals, restitutions, and net demand by macro-sector (by extracting sectors)

Macro-sector	Withdrawals (Mm^3)	Restitutions (Mm^3)	Net Demand (Mcm)
Agriculture	1011	146	864
Manufacture and Construction	502	356	146
Water Supply	647	105	542
Sewerage	0	248	-248
Services	0	0	0
Water for Dilution	620	0	620

Source: Own elaboration

Figure 6. Withdrawals by macro-sector and water source (by extracting sectors)



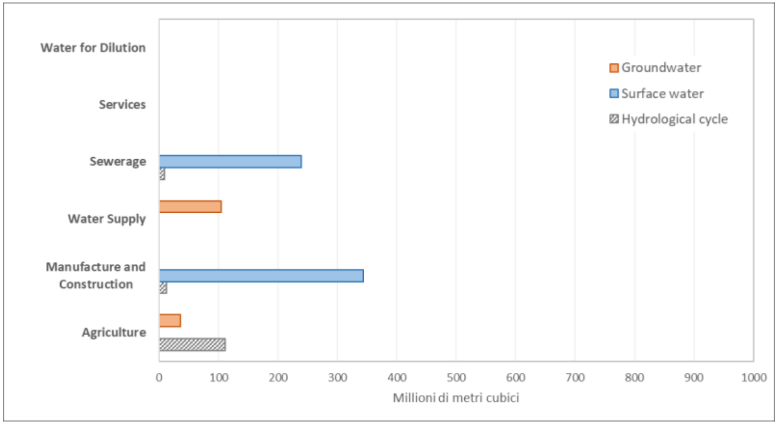
Source: Own elaboration

As expected, services do not show any direct linkage with the hydrological system: these production activities purchase water from the Water supply sector and discharge water through Sewerage service.

When looking at the hydrological balance classified by extracting sectors only agriculture shows a positive net demand of water from the hydrological cycle, due to the water supplied by rainfall that are incorporated in the final product).

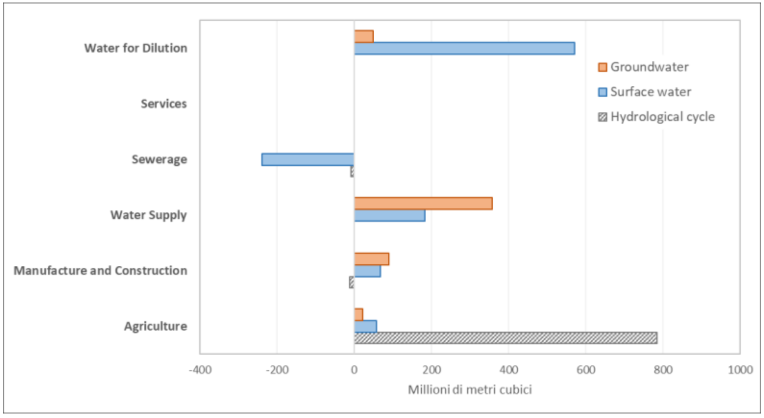
Both Sewerage services and manufacturing results as net suppliers net of water to the hydrological cycle. This is due to the natural losses generated by the discharge of water in the environment while these production activities don't receive water from the hydrological cycle.

Figure 7. Restitutions by macro-sector and water source (by extracting sectors)



Source: Own elaboration

Figure 8. Net demand by macro-sector and water source (by extracting sectors)



Source: Own elaboration

5.2 Water uses by demanding sectors

Table 10 shows the withdrawals, restitutions, and net demand for water for the five economic macro-sectors. In this case the net demand is classified by demanding sector, taking into account the "implicit" withdrawals and restitutions of water generated by the purchase of intermediate inputs
Water requirements for dilution are calculated at the level of the whole hydrological system and being not reclassified correspond to the non-reclassified case.
Figures 9, 10 and 11 show the results by source of water.

The net demand is now positive for all macro-sectors due to the reclassification from extracting to demanding sectors. Services show a

positive value both for withdrawals and restitutions, now interacting with all the three water bodies, though indirectly via the other production activities supplying intermediate inputs.
The net demand of water for both manufacture and service activities is positive also towards the hydrological cycle, due to the purchase of intermediate inputs from agriculture.

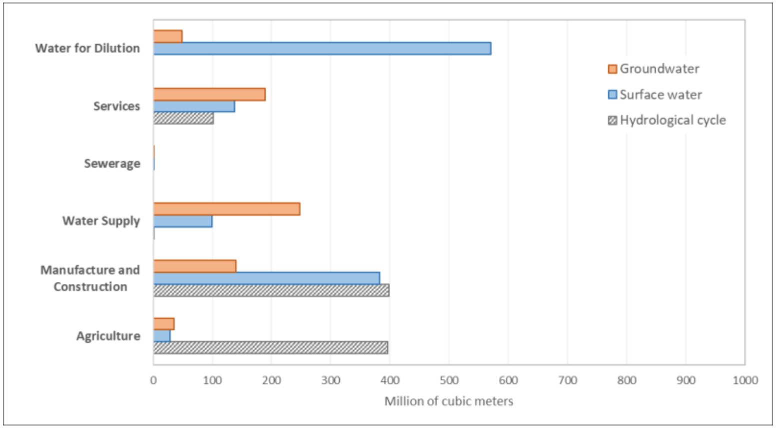
The complete breakdown of the components of the net demand of water by industry is available in the appendix of the paper.

Table 10. Withdrawals, restitutions, and net demand by macro-sector (by demanding sectors)

Macro-sector	Withdrawals (Mm^3)	Restitutions (Mm^3)	Net Demand (Mm^3)
Agriculture	460	92	368
Manufacture and Construction	921	403	518
Water Supply	348	57	291
Sewerage	0	158	-158
Services	428	140	288
Water for Dilution	620	0	620

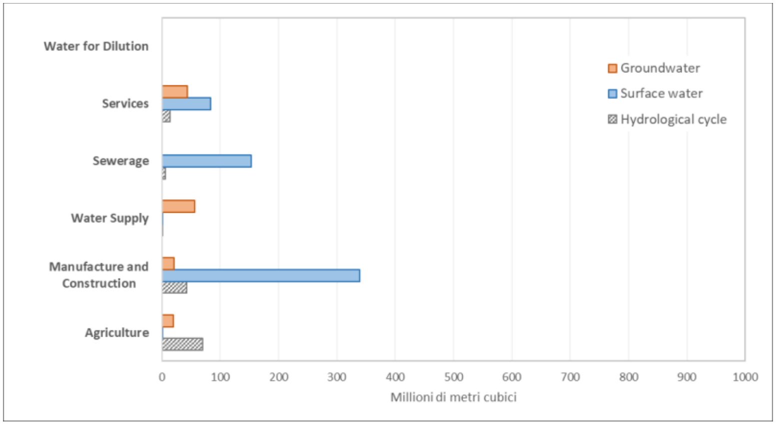
Source: Own elaboration

Figure 9 Withdrawals by macro-sector and water body (by demanding sectors)



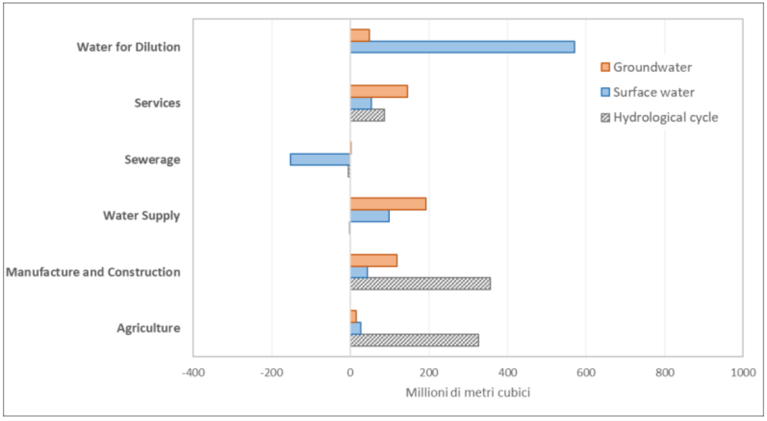
Source: Own elaboration

Figure 10. Restitutions by macro-sector and water source (by demanding sectors)



Source: Own elaboration

Figure 11. Net Demand by macro-sector and water source (by demanding sectors)

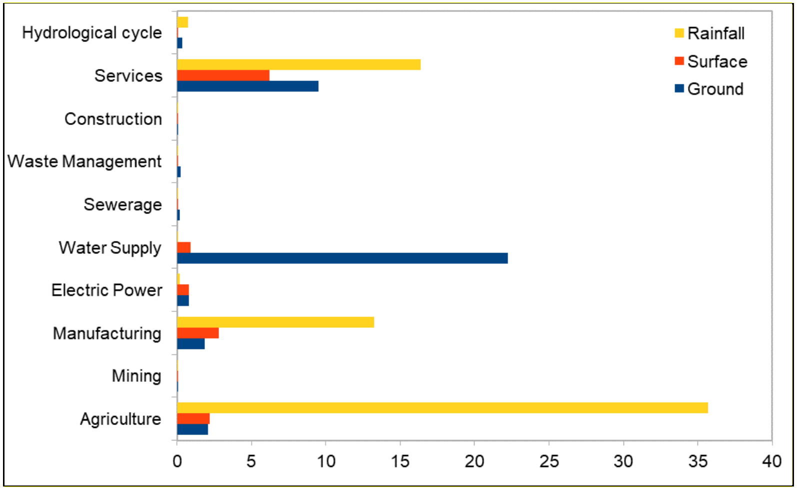


Source: Own elaboration

A complete and disaggregate representation of the relationships between economic activities and the hydrological system allows to use the model for in-depth analyses referring to specific sectors of the regional economy. For example, it is possible to map the impact on each hydrological body generated by the final demand directed towards a given industry through the sectors of the regional economy that are directly and indirectly activated.

An interesting example for Tuscany is the tourism sector, that in some period of the year is able to dramatically increase the population present in specific areas of the region.
According to the model the Tourism service sector account for the 7% of withdrawals of groundwater and 3% withdrawals of surface water. Figure 12 shows the breakdown of these withdrawals by demanding sectors.

Figure 12. Withdrawals generated by the final demand for touristic services reclassified by demanding sectors (Mm^3)



Source: Own elaboration

As the graph clearly shows the largest part of the pressures on groundwater resources is generated by purchases of touristic activities from water supply services. Interestingly, also agriculture and manufacturing (food industry) link in a relevant extent the demand of touristic services to pressure on water resources, both for ground and surface water (beside rainfall incorporated by agricultural products used to produce food supplied to tourists).

5.3 Economic pressure on water resources

The total net demand for water for the reference year (2017) corresponds to 1,926 Mm^3 (withdrawals minus restitutions). Table 11 shows the total net demand of the Tuscan economy divided by water source.

Table 11. Net demand by water source

Water Source	**Net Demand (Mm^3)**	**%**
Groundwater	519	26.9
Surface water	642	33.3
Hydrological cycle	764	39.7
Total	**1,926**	**100.0**

Source: Own elaboration

The calculation of the IPRI has been carried out both with natural and feasible supply. The natural supply corresponds to 8,723 Mm^3 while the feasible supply amount to 7,353 Mm^3. The feasible supply represents about 83% of the natural supply: the reduction is due to the constraints on supply associated with surface waters. In both cases 765 Mm^3 correspond to the precipitation captured directly by the macro-sector of agriculture.

Tables 12 and compares the IPRI with natural and feasible supply both for the total hydrological system and for single water body.

Table 12. IPRI with natural and feasible supply

Variable	Total water	Groundwater	Surface water
Net Demand	1,926	519	642
Natural Supply	8,723	4,155	3,803
Feasible Supply	7,353	4,155	2,434
IPRI with NS	**0.22**	**0.12**	**0.17**
IPRI with FS	**0.26**	**0.12**	**0.26**

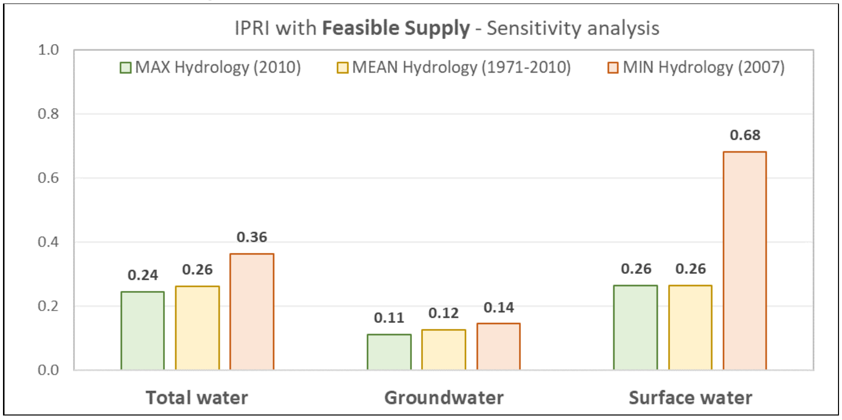
Source: Own elaboration

In the reference year the infiltration component of the natural supply was included in the interval assuring the maintenance of the groundwater stock in the long-run. Therefore, the feasible supply of groundwater is equal in the natural and feasible version of the IPRI.

The results show that at the regional level the overall use of water generated by the economy is largely compatible with the available water resources, also when natural, technical, and institutional constraints to water use are taken into account. However, as explained in section 3, the denominator of the IPRI ratio depends on the values that the components of the hydrological balance show in the considered year, compared with mean values of recharge and runoff. However, the components of the hydrological balance are random variables that can largely differ from the mean values both upward and downward. It could be interesting to assess what could have been the pressure on water resources in a year when natural components of the balance showed extreme values, given the structure of the economy observed in the reference year. Figures 13 shows the results of such a sensitivity analysis, comparing the IPRI with feasible supply calculated with reference to a mean hydrological situation and two extreme cases referring to the years with the best (2010) and the worst (2007) hydrological balance in the observed period.

Overall, the hydrological balance still shows at the aggregate level a wide coverage of net water demand by the supply, also taking into account the technological, institutional, and environmental constrains. However, the breakdown by water sources show relevant differences between ground and surface water supply. The former source faces a quite stable pressure due to the reservoir effect of the stock. Conversely, in the case of surface water, a worsening of the hydrological scenario could lead to a relevant increase of pressures almost tripling with minimum natural supply observed in the reference period (0.68 vs. 0.26 in the average hydrology scenario). Despite this value of IPRI still implies a wide safety margin between the net demand and the feasible supply, it should be considered that the regional average yearly value of the IPRI could hide a wide variability of the hydrological balance at the sub-regional level, with possible critical local situations.

Figure 13. Sensitivity analysis of IPRI with feasible supply
Mean hydrological balance vs. extreme years



Source: Own elaboration

6 DISCUSSION

The paper presented a multi-sector, environmentally extended input-output model representing in a detailed way the linkages between the economy and the hydrological system in Tuscany. Water flows between economic activities and the hydrological system (disaggregated by water body) have been taken into account both in terms of withdrawals and restitutions. Moreover, also the requirements of water necessary to maintain the qualitative balance of the hydrological system have been considered in calculating the net demand for water. The accounting framework proposed by Guan and Hubacek (2008) allowed to use a wide set of data from different sources to increase the quality of the empirical implementation of the model.

The model can support an in-depth analysis of the water footprint of the regional economy, for example to map the pressures on water resources from specific sectors of production activity to specific water bodies.

The results show that overall, the hydrological system of Tuscany is able to supply the water required by the regional economy. However, looking at such a result, it should be considered that the model allows to assess only an annual average scenario aggregated at the regional level. This could hide critical features of the hydro-economic regional system due to different source of variability.

First of all, the natural supply of water (and the corresponding hydrological scenario) presents a natural variability showing extreme situations even in absence of any specific climatic trends. A sensitivity analysis based on the natural variability of the regional hydrological balance in Tuscany during the last 40 years showed that the pressures on water resources could change in a relevant extent, mainly in the case of surface waters.

Second, the natural variability applies also *within* a single year. Average annual values for the components of the hydrological balance hide completely different situations within each single year in terms of natural and feasible supply of water. A sustainable average pressure on an annual basis could imply critical situations during periods of the year when the natural supply of water is lower.

Finally, both the economy and the hydrological system show an extreme geographic variability. The distribution of water intakes for irrigation presented in chapter 4 clearly show that the pressures on water resources depends on the location of production activities and the distribution of water resources across the regional territory. Critical local situations could be compatible with an overall sustainable balance between net demand and feasible supply of water at the regional level.

The three last considerations suggest also the needs for further refinement of the model. Both inter and intra-annual variability of the hydrological balance could be included in the model. This extension of the model could allow not only to associate to average results an assessment of their potential variability, but also to simulate the impact of climate change scenarios.

Furthermore, the breakdown of the model at the sub-regional level could allow to better assess the geographic distribution of impacts on water resources and the possible existence of local unsustainable situations within an overall sustainable regional scenario.

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8 APPENDIX

Table A.1. Water withdrawals and restitutions for 56 industries (by extracting sectors)

Sector	Macro-sector	Not Reclassified Withdrawals			Not Reclassified Restitutions		
		Groundwater	Surface water	Hydro Cycle	Groundwater	Surface water	Hydro Cycle
Arable land	Agriculture	11.0	11.8	208.8	5.6	0.0	8.4
Horticulture	Agriculture	10.9	5.1	146.3	10.0	0.0	42.1
Permanent crops	Agriculture	8.0	8.9	154.9	2.9	0.0	26.1
Grazing livestock	Agriculture	9.6	11.0	104.1	4.5	0.0	6.9
Granivores	Agriculture	1.7	3.5	23.8	1.4	0.0	2.2
Mixed crops farms	Agriculture	3.8	4.2	73.2	0.9	0.0	3.2
Mixed livestock farms	Agriculture	0.9	1.2	15.0	0.3	0.0	2.0
Mixed crops-livestock farms	Agriculture	11.4	11.9	169.9	9.9	0.0	20.0
Forestry and use of forest areas	Agriculture	0.0	0.0	0.0	0.0	0.0	0.0
Fishing	Agriculture	0.0	0.0	0.0	0.0	0.0	0.0
Mining and quarrying	Manufacturing	0.0	0.5	0.0	0.0	0.0	0.0
Food products and beverages	Manufacturing	27.7	0.0	0.0	0.0	16.9	0.6
Textiles	Manufacturing	0.0	64.1	0.0	0.0	24.5	0.9
Wearing apparel	Manufacturing	0.0	5.1	0.0	0.0	27.1	1.0
Leather and related goods	Manufacturing	0.0	24.7	0.0	0.0	40.0	1.5
Footwear	Manufacturing	0.0	1.8	0.0	0.0	18.2	0.7
Wood and wood products	Manufacturing	0.0	3.3	0.0	0.0	0.0	0.0
Paper Printing and rec. media	Manufacturing	0.0	48.2	0.0	0.0	36.1	1.3
Coke and refined petroleum products	Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0
Chemical and chemical products	Manufacturing	15.2	6.0	0.0	0.0	6.7	0.2
Pharmaceutical products	Manufacturing	15.8	6.3	0.0	0.0	6.8	0.2
Rubber and plastic products	Manufacturing	12.8	5.1	0.0	0.0	16.1	0.6
Other non-metallic products	Manufacturing	0.0	19.4	0.0	0.0	14.4	0.5
Manufacture of basic metals	Manufacturing	0.0	13.6	0.0	0.0	20.7	0.8
Metal products	Manufacturing	0.0	22.1	0.0	0.0	7.6	0.3
Computers, electronic and optical equipment	Manufacturing	0.0	2.6	0.0	0.0	2.0	0.1
Electrical equipments	Manufacturing	3.1	1.2	0.0	0.0	4.4	0.2
Machinery and equipment n.e.c.	Manufacturing	7.2	2.9	0.0	0.0	6.1	0.2
Motor vehicles and othe transportation means	Manufacturing	1.0	0.4	0.0	0.0	0.1	0.0
Furniture	Manufacturing	2.7	1.1	0.0	0.0	3.1	0.1
Jewelry	Manufacturing	0.8	0.3	0.0	0.0	5.3	0.2
Other manufacturing	Manufacturing	0.2	0.1	0.0	0.0	1.0	0.0
Repair and installation of equipment and systems	Manufacturing	3.6	1.4	0.0	0.0	1.2	0.0
Electricity power generation	Manufacturing	0.0	181.6	0.0	0.0	84.8	3.1
Electricity Transmission and Distribution	Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0
Gas Steam Air conditioning	Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0

Sector	Macro-sector	Not Reclassified Withdrawals			Not Reclassified Restitutions		
		Groundwater	Surface water	Hydro Cycle	Groundwater	Surface water	Hydro Cycle
Water supply	Water Supply	463.7	183.4	0.0	105.1	0.0	0.0
Sewerage	Sewerage	0.0	0.0	0.0	0.0	239.7	8.7
Waste management	Manufacturing	0.0	0.0	0.0	0.0	0.0	0.0
Construction	Construction	0.0	0.0	0.0	0.0	0.0	0.0
Wholesale and retail trade, repair of motor vehicle	Services	0.0	0.0	0.0	0.0	0.0	0.0
Transportation and storage	Services	0.0	0.0	0.0	0.0	0.0	0.0
Accommodation and food services	Services	0.0	0.0	0.0	0.0	0.0	0.0
Publishing, audiovisual, radio and television production	Services	0.0	0.0	0.0	0.0	0.0	0.0
Telecommunications	Services	0.0	0.0	0.0	0.0	0.0	0.0
IT and other information services	Services	0.0	0.0	0.0	0.0	0.0	0.0
Financial and insurance activities	Services	0.0	0.0	0.0	0.0	0.0	0.0
Real estate activities	Services	0.0	0.0	0.0	0.0	0.0	0.0
Professional and technical activities	Services	0.0	0.0	0.0	0.0	0.0	0.0
Scientific research and development	Services	0.0	0.0	0.0	0.0	0.0	0.0
Other service activities	Services	0.0	0.0	0.0	0.0	0.0	0.0
Public administration and defense; compulsory social security	Services	0.0	0.0	0.0	0.0	0.0	0.0
Education	Services	0.0	0.0	0.0	0.0	0.0	0.0
Health and social work activities	Services	0.0	0.0	0.0	0.0	0.0	0.0
Arts, entertainment, and recreation	Services	0.0	0.0	0.0	0.0	0.0	0.0
Other service activities	Services	0.0	0.0	0.0	0.0	0.0	0.0

Table A.2. Water withdrawals and restitutions for 56 industries (by demanding sectors)

Sector	Macro-sector	Reclassified Withdrawals			Reclassified Restitutions		
		Groundwater	Surface water	Hydro Cycle	Groundwater	Surface water	Hydro Cycle
Arable land	Agriculture	1.0	0.7	0.4	0.2	0.2	0.1
Horticulture	Agriculture	12.9	6.8	132.2	9.7	0.6	38.1
Permanent crops	Agriculture	7.0	6.9	94.1	2.3	0.4	15.8
Grazing livestock	Agriculture	0.8	0.8	7.0	0.3	0.1	0.4
Granivores	Agriculture	0.6	1.0	6.7	0.4	0.0	0.6
Mixed crops farms	Agriculture	2.7	2.8	46.1	0.6	0.1	2.1
Mixed livestock farms	Agriculture	0.6	0.6	5.2	0.2	0.0	0.6
Mixed crops-livestock farms	Agriculture	8.7	8.7	105.1	6.5	0.3	12.4
Forestry and use of forest areas	Agriculture	0.5	0.3	0.0	0.1	0.1	0.0
Fishing	Agriculture	0.0	0.2	0.0	0.0	0.1	0.0
Mining and quarrying	Manufacturing	0.1	0.7	0.2	0.0	2.2	0.1
Food products and beverages	Manufacturing	39.0	20.3	186.7	8.1	20.8	19.1
Textiles	Manufacturing	14.6	63.5	177.4	6.3	19.2	9.1
Wearing apparel	Manufacturing	0.7	15.0	0.1	0.1	29.9	1.1
Leather and related goods	Manufacturing	8.7	28.5	13.5	2.0	38.2	2.5
Footwear	Manufacturing	1.3	5.2	0.0	0.2	22.5	0.8
Wood and wood products	Manufacturing	0.2	5.5	0.4	0.0	2.6	0.1
Paper Printing and rec. media	Manufacturing	1.2	42.7	0.1	0.2	38.8	1.4
Coke and refined petroleum products	Manufacturing	0.7	3.2	0.6	0.1	3.9	0.2
Chemical and chemical products	Manufacturing	16.4	10.2	0.8	0.4	12.7	0.5
Pharmaceutical products	Manufacturing	16.7	8.1	2.4	0.2	11.1	0.7
Rubber and plastic products	Manufacturing	7.1	6.0	3.0	0.1	11.8	0.8
Other non-metallic products	Manufacturing	1.0	14.7	0.5	0.2	15.7	0.6
Manufacture of basic metals	Manufacturing	0.6	23.6	1.6	0.1	23.8	1.0
Metal products	Manufacturing	0.4	17.9	0.4	0.0	7.2	0.3
Computers, electronic and optical equipment	Manufacturing	3.6	4.8	1.8	0.8	3.4	0.3
Electrical equipments	Manufacturing	5.0	3.0	0.2	0.6	5.3	0.2
Machinery and equipment n.e.c.	Manufacturing	10.1	8.5	0.6	0.6	9.1	0.4
Motor vehicles and othe transportation means	Manufacturing	3.0	3.4	0.4	0.3	5.2	0.2
Furniture	Manufacturing	2.2	2.2	0.2	0.0	3.1	0.1
Jewelry	Manufacturing	1.1	1.6	0.0	0.1	6.4	0.2
Other manufacturing	Manufacturing	0.4	0.6	0.2	0.1	0.8	0.1
Repair and installation of equipment and systems	Manufacturing	2.2	2.8	0.4	0.0	1.7	0.1
Electricity power generation	Manufacturing	0.2	60.1	0.3	0.0	29.8	1.1
Electricity Transmission and Distribution	Manufacturing	0.1	16.6	0.0	0.0	8.1	0.3
Gas Steam Air conditioning	Manufacturing	0.3	12.0	3.9	0.1	5.6	0.6
Water supply	Water Supply	248.1	99.7	0.0	56.2	0.7	0.0
Sewerage	Sewerage	0.0	0.1	0.0	0.0	152.9	5.5
Waste management	Manufacturing	0.2	1.0	0.7	0.0	1.0	0.1

Sector	Macro-sector	Reclassified Withdrawals			Reclassified Restitutions		
		Groundwater	Surface water	Hydro Cycle	Groundwater	Surface water	Hydro Cycle
Construction	Construction	2.3	5.0	1.3	0.3	4.6	0.3
Wholesale and retail trade, repair of motor vehicle	Services	9.5	14.2	30.1	2.7	17.1	3.6
Transportation and storage	Services	1.5	8.1	2.9	0.3	11.9	0.8
Accommodation and food services	Services	26.2	18.8	46.7	6.1	6.5	5.4
Publishing, audiovisual, radio and television production	Services	0.0	0.2	0.2	0.0	0.6	0.0
Telecommunications	Services	2.0	1.3	0.2	0.4	0.8	0.0
IT and other information services	Services	0.4	0.6	0.2	0.1	1.1	0.1
Financial and insurance activities	Services	0.8	2.1	0.5	0.2	1.5	0.1
Real estate activities	Services	0.7	1.4	0.7	0.1	1.3	0.1
Professional and technical activities	Services	4.2	5.2	2.8	0.9	11.4	0.7
Scientific research and development	Services	1.2	3.6	2.4	0.3	2.2	0.3
Other service activities	Services	1.3	4.3	6.6	0.3	3.8	0.9
Public administration and defense; compulsory social security	Services	134.4	57.8	1.5	30.5	2.4	0.2
Education	Services	2.1	3.1	1.1	0.5	1.1	0.2
Health and social work activities	Services	3.3	6.7	1.7	0.6	16.7	0.8
Arts, entertainment, and recreation	Services	0.8	2.4	2.3	0.2	1.3	0.3
Other service activities	Services	0.5	7.5	1.7	0.1	3.6	0.3
Groundwater		42.8	0.0	0.0	0.0	0.0	0.0
Surface waters		0.0	564.1	0.0	0.0	0.0	0.0
Natural contributions		6.0	6.7	0.0	0.0	0.0	0.0