HYDRO-ECONOMIC EQUILIBRIUM AND TERRITORIAL SCOPE OF WATER POLICY IN THE LOCAL SYSTEMS OF TUSCANY, ITALY.

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Abstract

This article analyzes the sustainable exploitation of water in the Tuscany region of Italy from a different approach than that traditionally used. In general, interregional input-output models use spatial scales defined with political-economic criteria, however, these spatial units do not correspond to the natural unit of analysis of water management: the hydrographic basin. Using the IRIO matrix of Tuscany at the scale of local labor systems (LLS), in this work environmentally extended IRIO models are developed at the basin and sub-basin level, adding LLS. From the characterization of the hydroeconomic balance (HEE) and its cost (CHEE), considering the historical hydrological structure and a climate change scenario (100 years in each case), it is possible to identify the spatial scope that the water policies associated with each LLS, and the economic benefit of them in terms of greater production without overexploiting water. The scope of the water policy is defined by the territorial extension (LLS, sub-basin, basin or region) in which it is possible to manage water in a sustainable way and thus be able to ensure the HEE in each LLS.

Key words: hydro-economic equilibrium, interregional input-output hydrological scales, water policy, Tuscany

JEL Classification: C67, Q25, Q50

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1 Introduction

The Tuscany region (Italy) does not present major issues in terms of water stress when analyzed at a regional scale (Venturi, 2014; Rocchi and Sturla, 2021). Sturla and Rocchi (2022a) demonstrated that when the regional economy is faced with 100 hydrological years, water exploitation indicators never exceed scarcity thresholds.

However, this regional perspective conceals significant spatial heterogeneities (Figure 1). Greater availability of surface and groundwater is found in the northern and northeastern areas. Water demand primarily concentrates in the central part of the region (74% of GDP).

To address this spatial variability, Sturla and Rocchi (2022b) studied the hydro-economic equilibrium (HEE) at the local labor systems (LLS) level using an interregional input-output hydroeconomic model. The study considers 49 LLS (Figure 2) and estimates the extended water exploitation indicator (EWEI) for 100 years, comparing it with scarcity thresholds (STg).

Sturla and Rocchi (2022b) found that 16 LLS are not in hydroeconomic equilibrium. When climate change hydrology is considered, the LLS outside the HEE increases to 19.

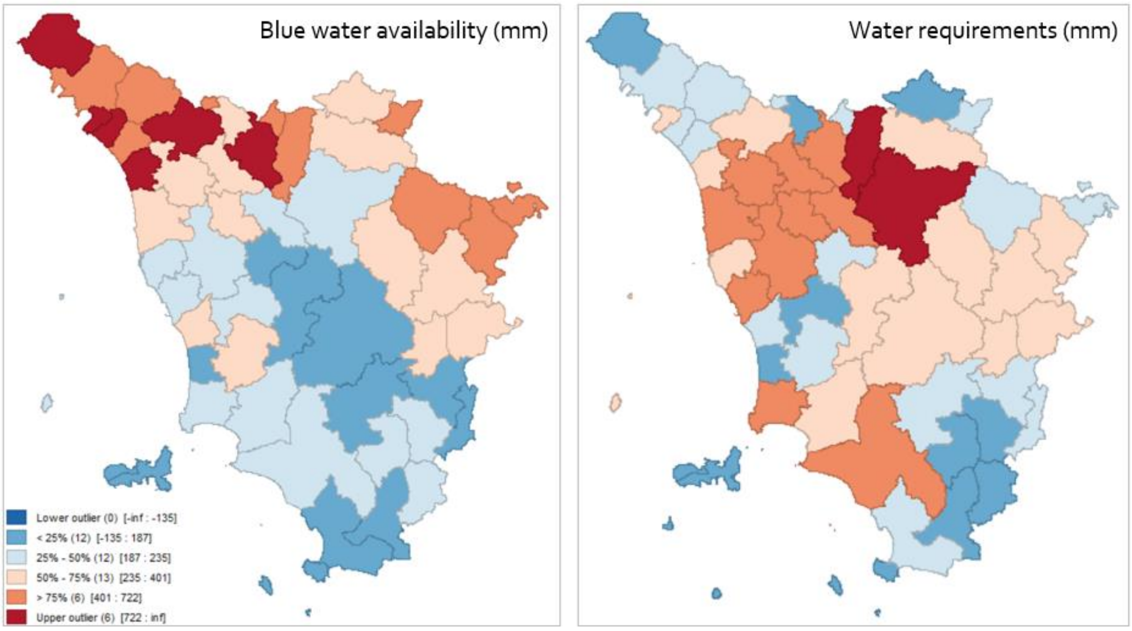
LLS are defined as aggregates of municipalities based on economic, which is not a hydrological criteria. For LLS that could face water scarcity issues, sustainable resource management policies are required, which could be formulated at the local, watershed, river basin, or regional level.

In this context, an interesting research question arises: What are the characteristics of hydroeconomic equilibrium when considering hydrological spatial scales, and how does this determine the territorial scope of water policies in each LLS?

Therefore, this study aims to conduct an integrated economic-ecological analysis at the basin and sub-basin level to evaluate whether HEE is achieved in the analyzed spatial units. The objective is to determine the most suitable territorial scope for designing sustainable water management policies, considering the base hydrological scenario (historical) and a climate change hydrological scenario.

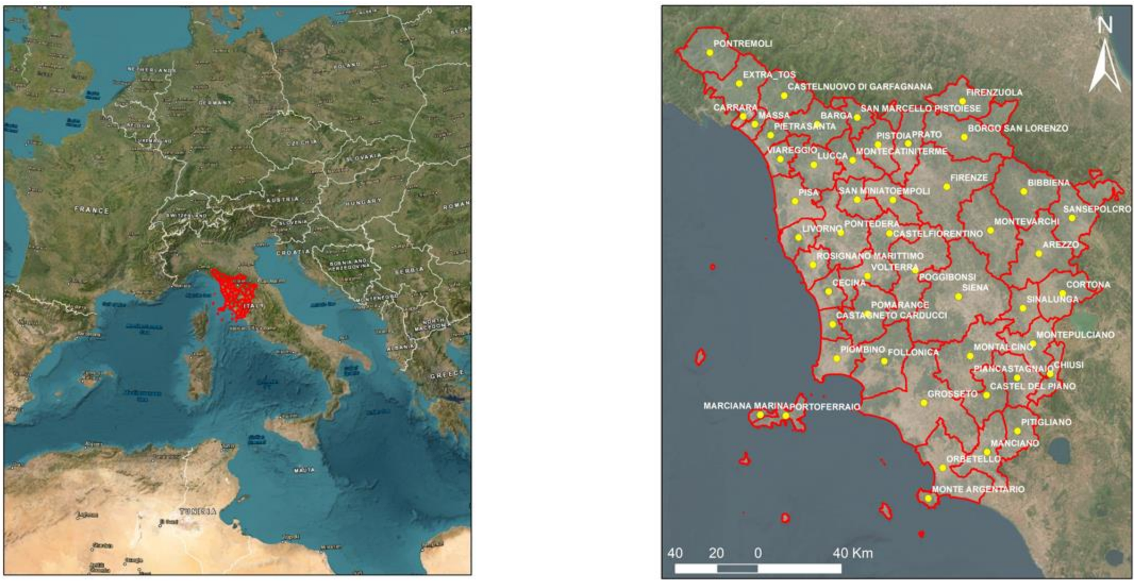
Another aspect of interest corresponds to the cost of hydroeconomic equilibrium (CHEE). Sturla and Rocchi (2022b) propose this concept and estimate it by calculating the minimum reduction in production (value in monetary units) necessary for all LLS to be in HEE. In other words, the CHEE reflects the value of production that is based on the overexploitation of water resources. Sturla and Rocchi (2022b) calculated the CHEE at the LLS scale for mean hydrological conditions (). Estimating the CHEE for the sub-basin and basin scales, considering 100 hydrological years (base hydrology and climate change), allows quantifying the economic-environmental benefit of water management at hydrological scales. This work also aims to quantify this benefit based on the analysis at different spatial scales.

Figure 1. Spatial heterogeneities water availability and requirements



Source: Own elaboration

Figure 2. LLS of Tuscany, Italy.



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2 METHODOLOGY

The analysis considers 4 basins and 10 sub-basins (Figure 3), assigning the 49 SLLs of the region to them (Figure 4), taking into account their area and existing hydraulic interconnections (AIT, 2023; ADAS, 2021).

Two interregional input-output matrices (56 economic sectors) are constructed based on the aggregation of the matrix at the LLS scale (IRPET, 2021). The sectoral coefficients of water use (blue water) and the parameters associated with water for dilution (gray water) are obtained from the study of Sturla and Rocchi (2022b).

Hydrological component matrices are developed for basins and sub-basins, considering precipitation, evapotranspiration, surface runoff, and groundwater recharge. These matrices contain simulations for 100 hydrological years based on a spatial stochastic hydrological model (D'Oria et al., 2019; Pranzine et al., 2020; Sturla and Rocchi, 2022b). Based on these matrices, the feasible water supply is calculated and variability is introduced to the input-output model (Sturla and Rocchi, 2022b).

Following the methodology proposed by Sturla and Rocchi (2022b), an interregional hydroeconomic model is constructed to estimate the extended water exploitation index (EWEI) and the scarcity threshold (STg) for each unit of analysis and hydrological year.

The EWEI corresponds to the quotient between the demand for water and the feasible supply for water, estimated for each unit of analysis (LLS, sub-basin, basin and region).

$$EWEI_t^S = \frac{\sum_{i=1}^{m}\sum_{k=1}^{2}(f_{k,i,t}^s - r_{k,i,t}^s + w_{k,i,t}^s)\cdot x_i^s}{I_t^{s,feas} + R_t^{s,feas}} \quad (1)$$

where the sums considers m industries and two water bodies (groundwater and surface water). $I_t^{s,feas}$ and $R_t^{s,feas}$, are the groundwater and surface water feasible supplies. The coefficients $f_{k,i,t}^s$, $r_{k,i,t}^s$ and $w_{k,i,t}^s$ correspond to the water extracted, restored and gray water by unit of output, for the industry i, water body k, year t and spatial unit s, respectively. x_i^s corresponds to the production of the industry in in the spatial unit s.

The EWEI for each spatial unit is compared with the STg. The latter is estimated based on the methodology proposed by Sturla and Rocchi (2022b), which considers as a criterion that in none of the months of the year the demand for water is less than the feasible supply. For each spatial unit, 100 values are estimated for the EWEI and one value for the STg, both for base hydrology and for climate change.

This study defines sustainability criteria as the situation where the EWEI does not exceed the threshold by more than 15 years (out of 100 years). That is, a spatial unit is in hydroeconomic equilibrium HEE if this condition is met.

For the purposes of calculating the cost of hydroeconomic equilibrium (CHEE), this is estimated 100 times for each analysis (LLS, sub-basin, basin and region) and each hydrological scenario (baseline and climate change). The CHEE corresponds to the minimum reduction in regional production, such that all spatial units are in HEE. For its calculation, the optimization procedure described in Sturla and Rocchi (2022b) is used. The only difference is that Sturla and Rocchi (2022b) estimate the CHEE for the medium condition. In this work it is estimated for each year.

The territorial scope of water policies is determined based on the spatial unit where water availability management required by an LLS for sustainable resource use must be addressed. Thus, four types of territorial scope are defined:

- Local Scope: if the SLL is in HEE
- Sub-basin Scope: If the SLL is not in HEE, but the sub-basin is in HEE
- Basin Scope: If neither the SLL nor the sub-basin is in HEE, but the basin is in HEE
- Regional Scope: If neither the SLL, sub-basin, nor basin is in HEE

Figure 3. Basins and Sub-basins in Tuscany

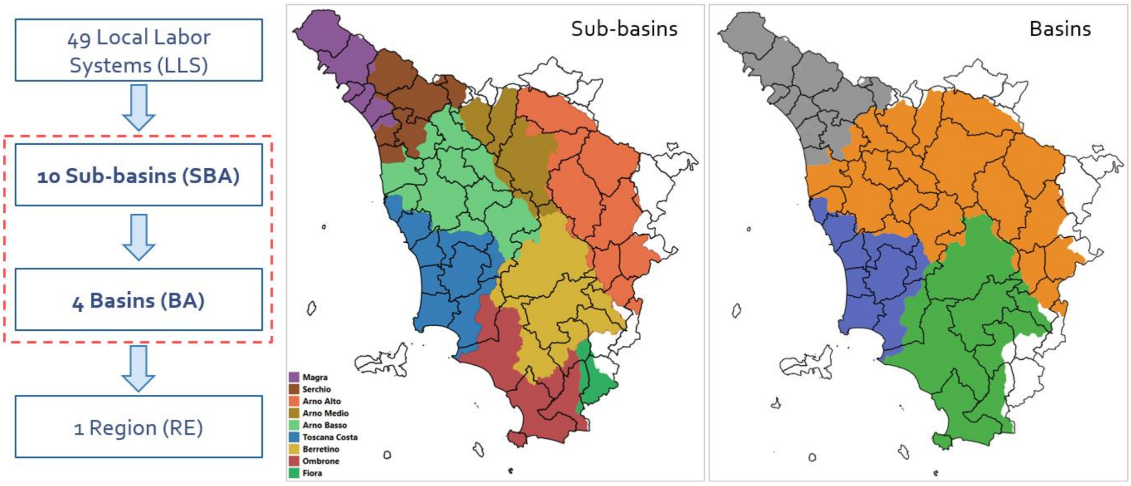

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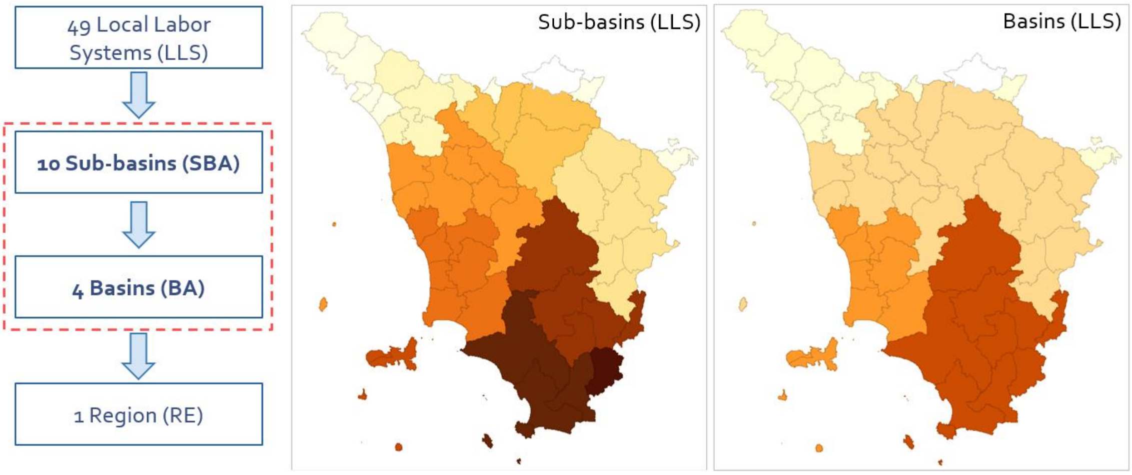
Figure 4. Aggregation of LLS by Basins and Sub-basins



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3 RESULTS

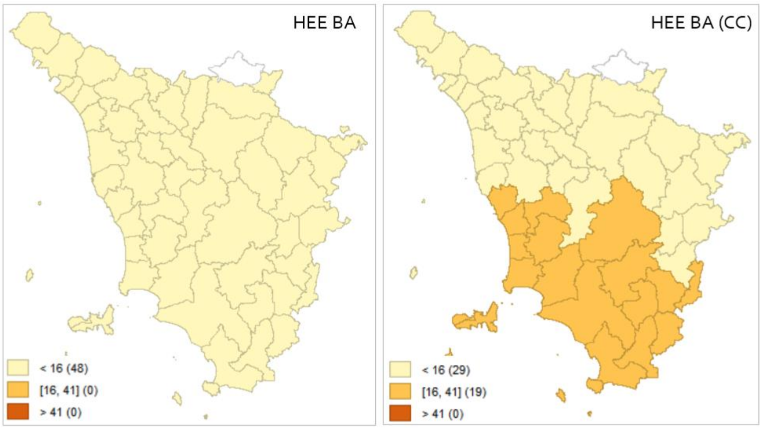
The EWEI and STg have been estimated for the scale of basins and sub-basins, considering base hydrology and climate change. There are 100 EWEI values and one STg value for each hydrological scenario.

When the scale of basins (Figure 5) and base hydrology are considered, in none of the four basins the sustainability criterion is exceeded (EWEI greater than STg more than 15 times in 100 years). However, when is considered the climate change hydrology, the Ombrone (southern Tuscany) and Toscana-Costa basins present imbalances in more than 15 years. This implies that management at the water basin level could allow sustainable use of water resources only in the case with normal hydrology. When considering the climate change scenario, managing the water supply within the basins is not enough.

When considering the scale of sub-basins (Figure 6), two sub-basins are not in HEE (Toscana Costa and Ombrone Basso). When considering the hydrology of climate change, the Arno Basso sub-basin is incorporated to this condition. For the LLS that are located in sub-basins in HEE, the maximum spatial scope of the water policy would be that associated with the sub-basins.

Figure 5. Hydroeconomic equilibrium in Basins

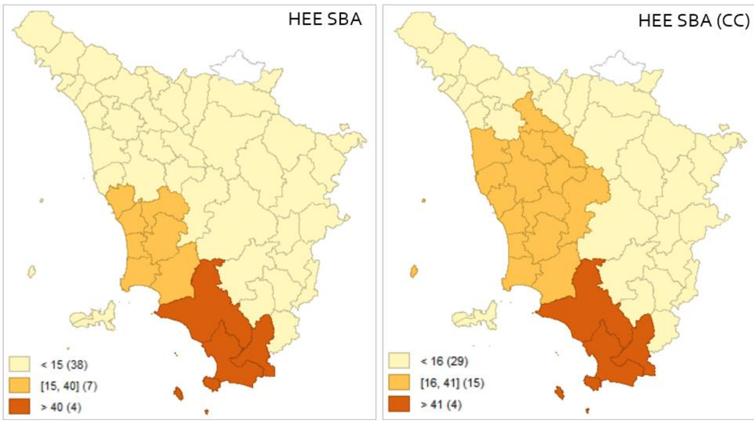
Basins (BA)	Freq. EWEI > STg (BASE)	Freq. EWEI > STg (CC)
Arno	0	0
Toscana Costa	15	34
Magra-Serchio	0	0
Ombrone	3	18



Source: Own elaboration

Figure 6. Hydroeconomic equilibrium in Sub-basins

Sub-basins (SBA)	Freq. EWEI > STg (BASE)	Freq. EWEI > STg (CC)
Arno Alto	0	3
Arno Basso	5	36
Arno Medio	0	0
Berretino	0	0
Fiora	0	0
Elba	0	0
Magra	0	0
Reno	0	0
Serchio	0	0
Toscana Costa	20	39
Ombrone Basso	41	52



Source: Own elaboration

Based on the estimation of the HEE by basins and sub-basins, it is possible to define the territorial scope of the water policies required in each LLS to achieve sustainability, assuming the possibility of managing and/or reordering the uses of water within the hydrological units.

For the base hydrological scenario, 33 LLS require a local water policy (they are in HEE), 19 LLS require management at the sub-basin level, and 6 LLS require management at the basin level (Figure 7).

When considering the hydrological scenario of climate change, 30 LLS require a local policy, 8 LLS require management at the sub-basin level, 4 LLS require management at the basin level and 7 LLS require regional management (Figure 8 and Figure 9). The impact of climate change on the territorial scope of water policy implies the need for water management at larger spatial scales.

Figure 7. Territorial scope of water policy by LLS

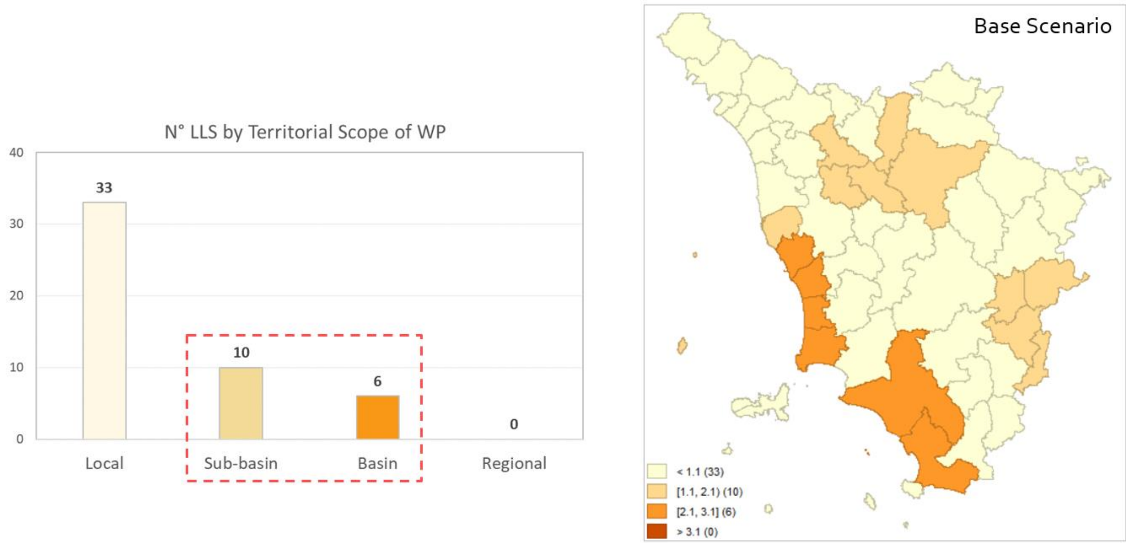


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Figure 8. Territorial scope of water policy by LLS. Base and Climate Change Scenario

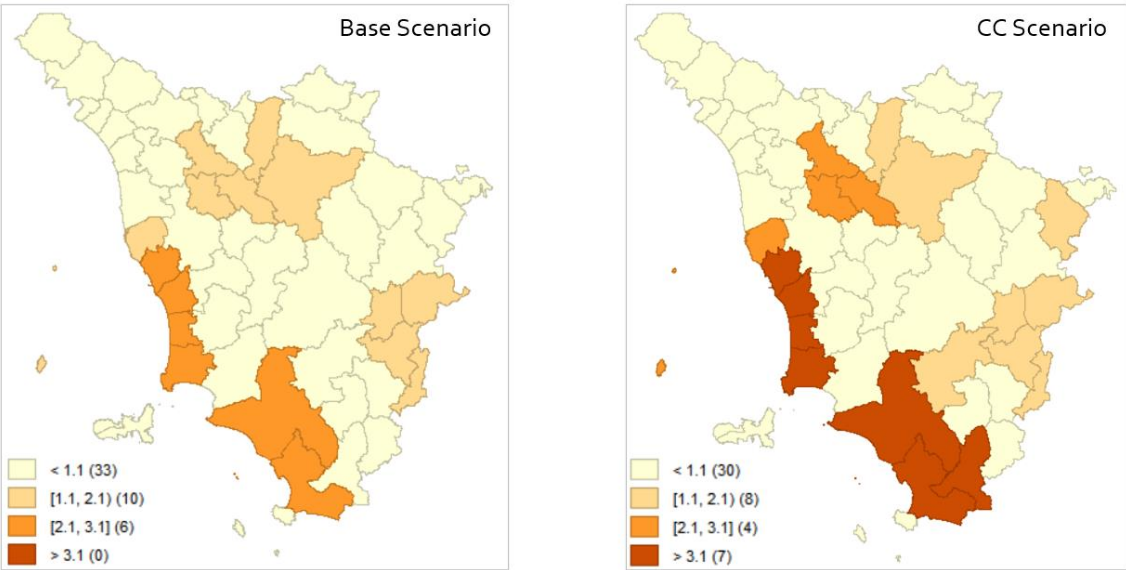

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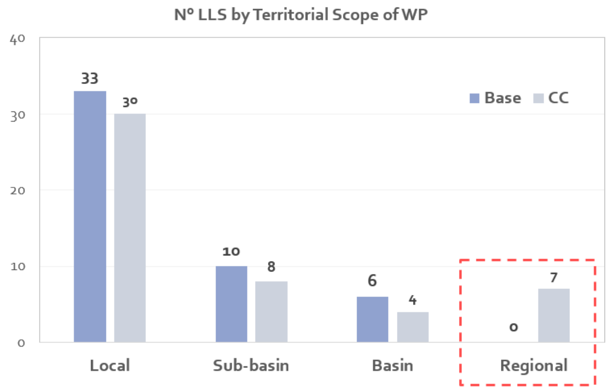
Figure 9. Change in territorial scope of water policies because of Climate Change



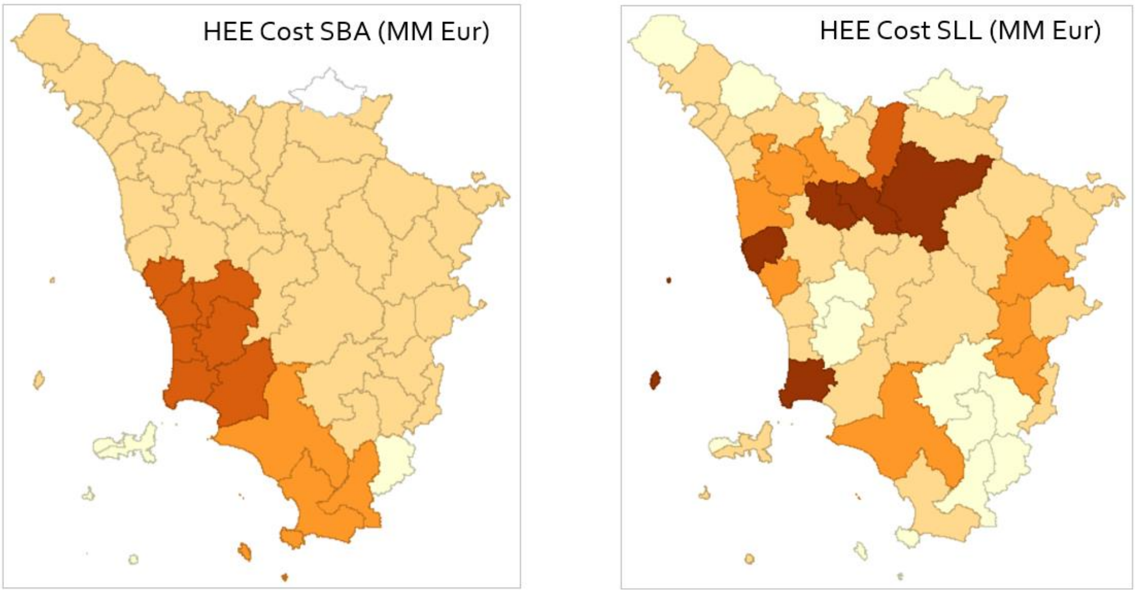
Change of TSWP	N°LLS
LLS-SBA	2
LLS-RE	1
SBA-BA	4
BA-RE	6

Source: Own elaboration

When the cost of the HEE is calculated for the base scenario, the cost is zero for the regional scale and for the basin scale (all basins are in HEE). The costs are positive at the sub-basin and LLS level (Figure 10). When considering the sub-basin scale, the CHEE amounts to 2,602 million euros, and when considering the LSS scale, the CHEE is 22,539 million euros (Table 1). This means that the benefits of good water management at the sub-basin level could total 25,141 million euros, estimated as the value of production that would no longer be supported by the overexploitation of water. In other words, the cost of not carrying out adequate management at the sub-basin level implies that 25,141 million euros of production impact the water environment.

When considering climate change, the CHEE (Table 1) is no longer zero for the basin level (two of them are not in HEE). The CHEE for this scale is 1,996 million euros. For the sub-basin level, the CHEE is 8,038 million euros and for the LLS level it is 26,657 million euros. In the case of LLS, the economic impact of climate change implies an increase in production supported by the overexploitation of water by 4,118 million euros. In the case of the sub-basins this amount is 5,436 million euros. These results imply that the economic-environmental benefits of water management at the sub-basin and basin level will be much greater for a climate change hydrology.

Figure 10. Cost of the HEE at Sub-basin and LLS scales



Source: Own elaboration

Table 1. Cost of the hydroeconomic equilibrium

		N° Units not in HEE		HEE Cost (million euros)	
Aggregation Level	N° Units	**Base Scenario**	**CC Scenario**	**Base Scenario**	**CC Scenario**
Region	1	0	0	0	0
Basins	4	0	2	0	1,996
Sub-basins	10	2	3	2,602	8,038
Local systems	49	16	19	22,539	26,657

Source: Own elaboration

4 CONCLUSIONS

This article studies sustainability in water use in the Tuscany region of Italy, considering different spatial scales. In particular, two hydrological scales, the basin and the sub-basin, have been added to the scales of local labor systems (the most fine scale) and the regional scale.

Using an interregional input-product model extended to water, the spatial units that are in HEE for a base hydrological condition and for climate change are identified. In both cases, 100 hydrological years are considered. Furthermore, through an optimization methodology, the CHEE is estimated for the different spatial scales. This cost represents the production that must be reduced (optimally) so that no spatial unit is outside the HEE.

By incorporating the basin and sub-basin scales (adding the LLS) it is possible to carry out a more coherent analysis with the water reality. This allows defining the spatial scope of water policies, required by each LLS in Tuscany to address the problems of water overexploitation.

Results for the base hydrological scenario a indicate that 2 out of 10 sub-basins do not meet HEE, while all basins do. When considering the climate change availability scenario, sub-basins increase to 3, and basins without HEE are 2 out of a total of 4.

Regarding the territorial scope of water policies, results indicate that 33 SLLs require Local Scope management, 10 require Sub-basin Scope, and 6 require Basin Scope. When considering climate change, 30 SLLs require Local Scope, 8 require Sub-basin Scope, 4 require Basin Scope, and 7 SLLs require Regional Scope.

By estimating the CHEE it is possible to quantify the economic benefit in terms of the value of additional production without water impact. For base hydrology, management at the sub-basin level reports a benefit of 25,141 million euros and management at the basin level a benefit of 2,602 million euros. When climate change is considered, management at the sub-basin level reports a benefit of 18,619 million euros, management at the basin level a benefit of 6,042 million euros, and regional management a benefit of 1,996 million euros.

The results show significant sub-regional heterogeneity not only concerning the balance between water demand and supply at different spatial scales but also regarding the required territorial scope for policies. This heterogeneity increases when considering the effects of climate change on water availability.

The proposed study represents a contribution to the literature of input-output analysis applied to environmental problems. This, fundamentally, due to the incorporation of hydrological spatial scales in the analysis. By incorporating these scales, the relationship between the productive system and the water system becomes more coherent.

Based on the results of this work, it is possible to define water sustainability policies within the region, considering their most beneficial or optimal spatial scope. The developed model allows, in turn, to evaluate the water and economic impact of these policies. In this way, the study serves as a basis for water policy makers in the region.

As future work, it is possible to enrich the model by incorporating more climate change scenarios, in order to better evaluate the expected changes, both in the scope of the water policy and in the CHEE. This improvement of the model will allow, for example, the design and evaluation of water infrastructure to mitigate the effects of climate change in the region. And, on the other hand, considering that the situation of overexploitation is more complex in the Toscana Costa basin, it would be beneficial to do a more complete study in this area, also considering the fact that the demand for water for domestic use is very variable during year; it is increased in the summer months by tourism. In addition to the intra-annual variability of demand associated with agriculture, including the intra-annual variability of domestic water demand would allow for a better characterization of the HEE and its cost.

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