HYDRO-ECONOMIC EQUILIBRIUM WITH CLIMATIC VARIABILITY IN A SUBREGIONAL INPUT-OUTPUT FRAMEWORK: THE CASE OF TUSCANY

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An input-output hydro-economic model to assess the economic pressure on water resources

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Natural and social scarcity in water Footprint: A multiregional input–output analysis for Italy

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Sustainable Production and Consumption
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ELSEVIER

Estimating the global production and consumption-based water footprint of a regional economy

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Our approach

- A comprehensive accounting framework for water flows between economy and water bodies (water *use* as in the volumetric approach to WF)
- Uses are measured against availability to model water *pressures* (as in the LC approach to WF)
- The IO structure of the economy allows to model *implicit water flows* among sectors and regions
- We include the *natural variability* of the hydrological system

Innovative features

- Water demand of each economic activitiy includes quantities necessary to ensure the minimum quality of surface water bodies after discharges (*grey water requirements*: cfr. Guan and Hubaceck, 2008)
- The variability of water demand includes *endogenous components* (e.g. inverse relation of precipitations and water demand for irrigation)
- Water supply includes technical, institutional and environmental constraints (*environmental relevance* of water pressures as in the LC approach to WF)

MRIO multi-LMA table

- 53 industries, 49 LMA

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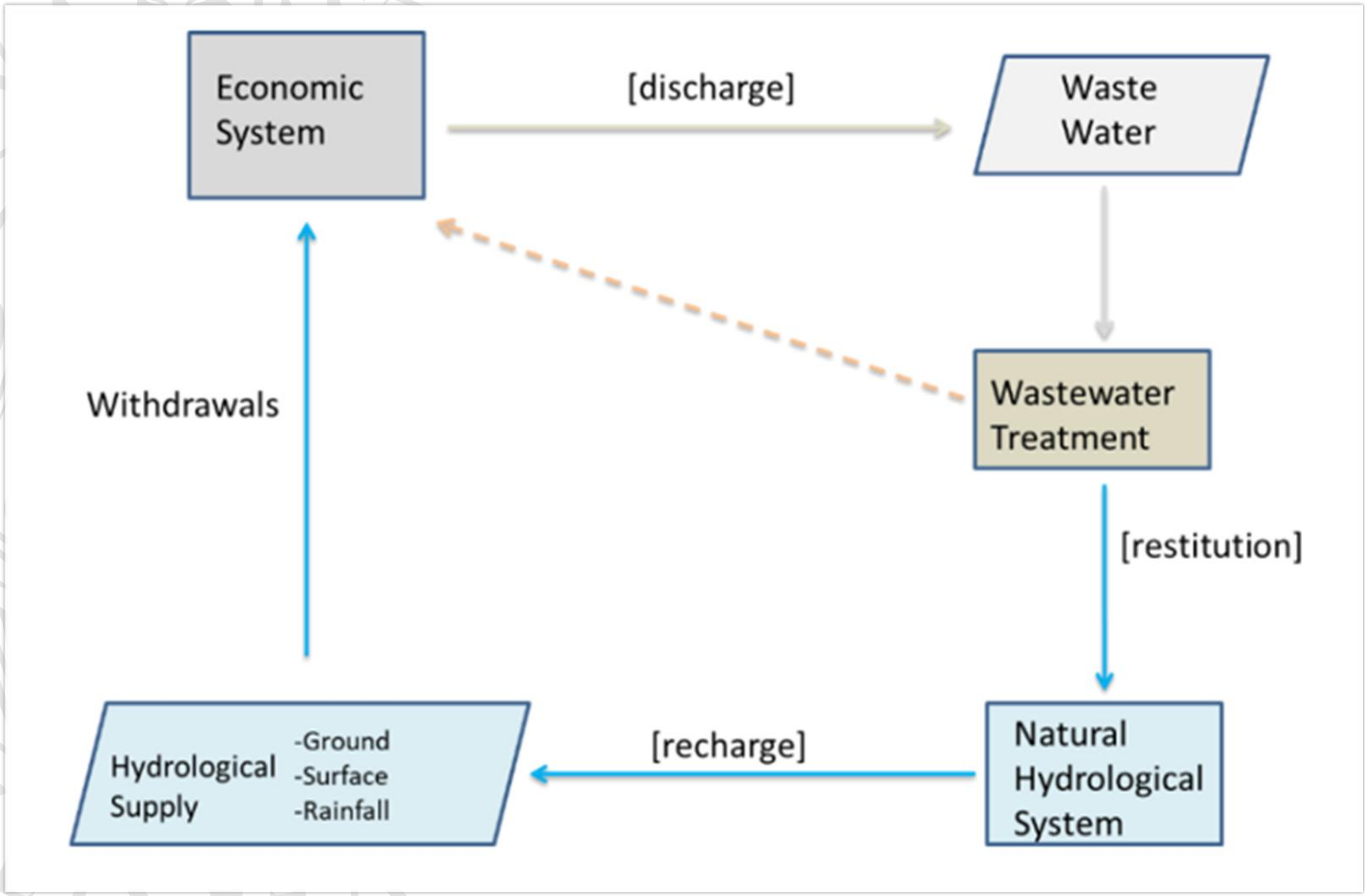
		SCAMBI INTERMEDI						DOMANDA FINALE										OUTPUT
		901	902	....	....	948	999	901	902	...	...	948	999	Variazione Scorte	Export Resto Italia prodotti intermedi	Export Resto Italia prodotti Finali	Export Estero	
SCAMBI INTERMEDI	901																	
	902																	
	....																	
	....																	
	948																	
	999																	
Valore Aggiunto																		
Imposte Prodotti																		
Importazioni Resto Italia																		
Importazioni ESTERO																		
OUTPUT																		

The logical structure of the model



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Research questions

- What is the average (yearly) level of pressure on water resources beyond which critical situations of water scarcity are likely to emerge?
- What are the conditions for a hydro-economic equilibrium in the region, given the structure of the economy and the endowment of water resources?
- What is the opportunity cost of such hydro-economic equilibrium?

An «extended» water demand

- Some definitions
  - Net demand: withdrawals - discharges
  - Extended demand: net demand + water for dilution
  - Reclassified demand: direct use of water - implicit sales of water + implicit purchases of water

- This concepts are applied for each industry in each Local Market Area (LMA)

A «feasible» supply of water

- Considers environmental (ecological flow), technological (hydraulic works) and institutional (concessions) limitations to natural water supply

$$R_t^{feas} = \begin{cases} R_t - E\bar{R} & if \;\; E\bar{R} < R_t < M\bar{R} + E\bar{R} \\ M\bar{R} & if \;\; R_t > M\bar{R} + E\bar{R} \\ 0 & if \; R_t < E\bar{R} \end{cases}$$

$$I_t^{feas} = \begin{cases} \bar{I}(1-B) & if \;\; I_t < \bar{I}(1-B) \\ \bar{I}(1+B) & if \;\; I_t > \bar{I}(1+B) \\ I_t & if \;\; I \in [\bar{I}(1-B), \bar{I}(1+B)] \end{cases}$$

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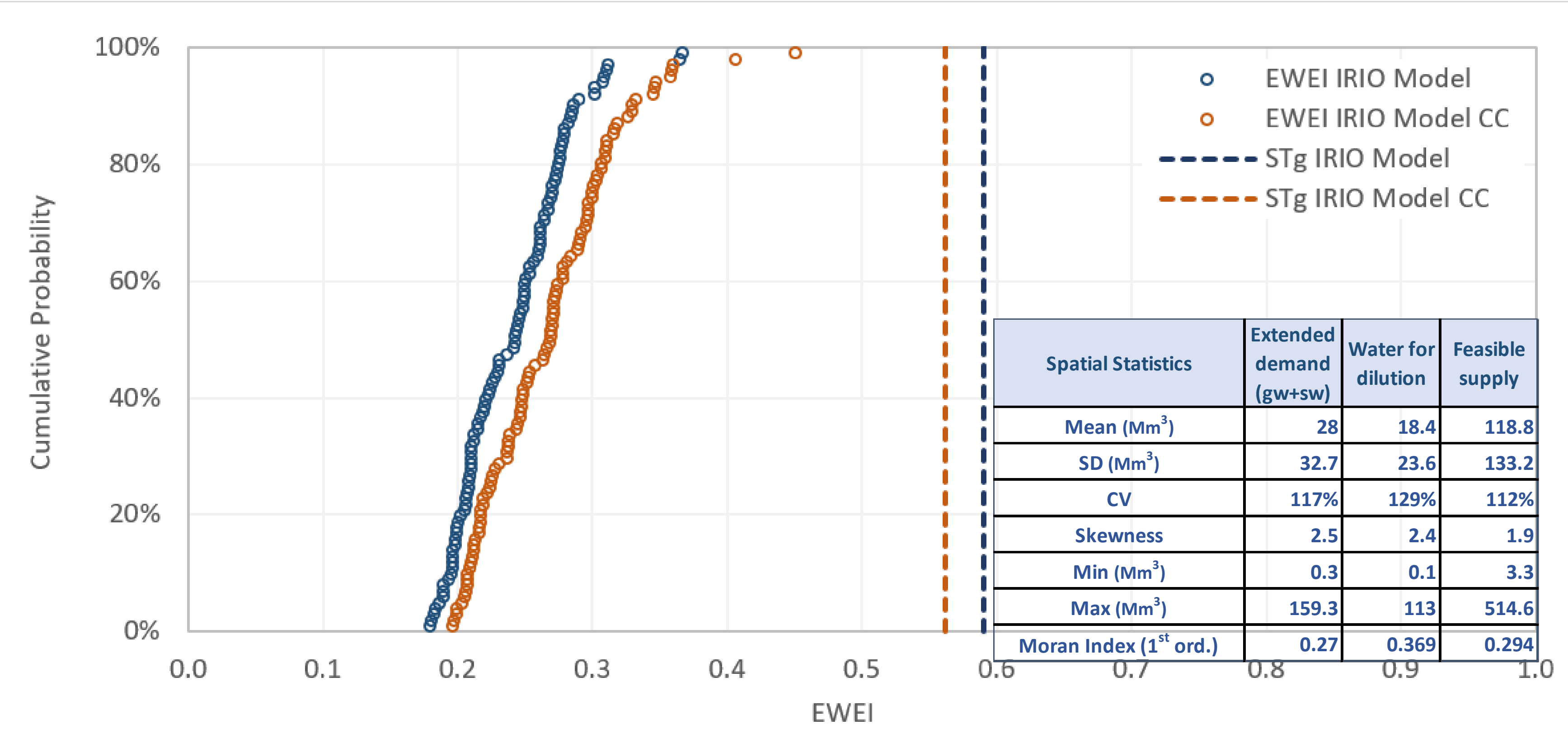
Extended Water Exploitation Index

Figure 1. EWEI cumulative probability distribution and Scarcity threshold

Whole Tuscany - Base and Climate Change scenario



Spatial Statistics	Extended demand (gw+sw)	Water for dilution	Feasible supply
Mean (Mm^3)	28	18.4	118.8
SD (Mm^3)	32.7	23.6	133.2
CV	117%	129%	112%
Skewness	2.5	2.4	1.9
Min (Mm^3)	0.3	0.1	3.3
Max (Mm^3)	159.3	113	514.6
Moran Index (1st ord.)	0.27	0.369	0.294

Source: own elaborations

$$EWEI = \frac{i \sum_{k=1}^{2} \left(\hat{f}_k - \hat{r}_k + \hat{w}_k\right)' (I - A_d)^{-1} y}{I^{feas} + R^{feas}}$$

Intra-annual EWEI

$$EWEI_i^s = \frac{(1-\alpha^s) + \alpha^s a_i^s}{(1-\beta^s)c_i^s + \beta^s b_i^s} EWEI^s$$

$\alpha^s = \frac{ED_{Var}^s}{ED^s}$ is the share of the extended demand corresponding to industries with intra-annual variability

$\beta^s = \frac{FS_{sw}^s}{FS^s}$ is the share of surface water feasible supply

$a_i^s = \frac{ED_{Var,i}^s}{ED_{Var}^s/12}$ is the intra-annual distribution coefficient of the extended demand from industries with intra-annual variability for month *i*

$b_i^s = \frac{FS_{sw,i}^s}{FS_{sw}^s/12}$ is the intra-annual distribution coefficient of surface water feasible supply for month *i*

$c_i^s = \frac{FS_{gw,i}^s}{FS_{gw}^s/12}$ is the intra-annual distribution coefficient of groundwater feasible supply for month *i*

Endogenous scarcity thresholds

$$ST^s = \min_i \frac{(1-\beta^s)c_i^s + \beta^r b_i^s}{(1-\alpha^s) + \alpha^s a_i^s}$$

The sub-regional scarcity threshold corresponds to the annual EWEI ensuring that the EWEI will be equal to 1 in the critical month, i.e. the month with the smaller difference between supply and demand, and less or equal than 1 for the other months.

Hydro-economic equilibrium

$$\max_{\phi} \; e' \cdot L \cdot \hat{\phi} \cdot d$$

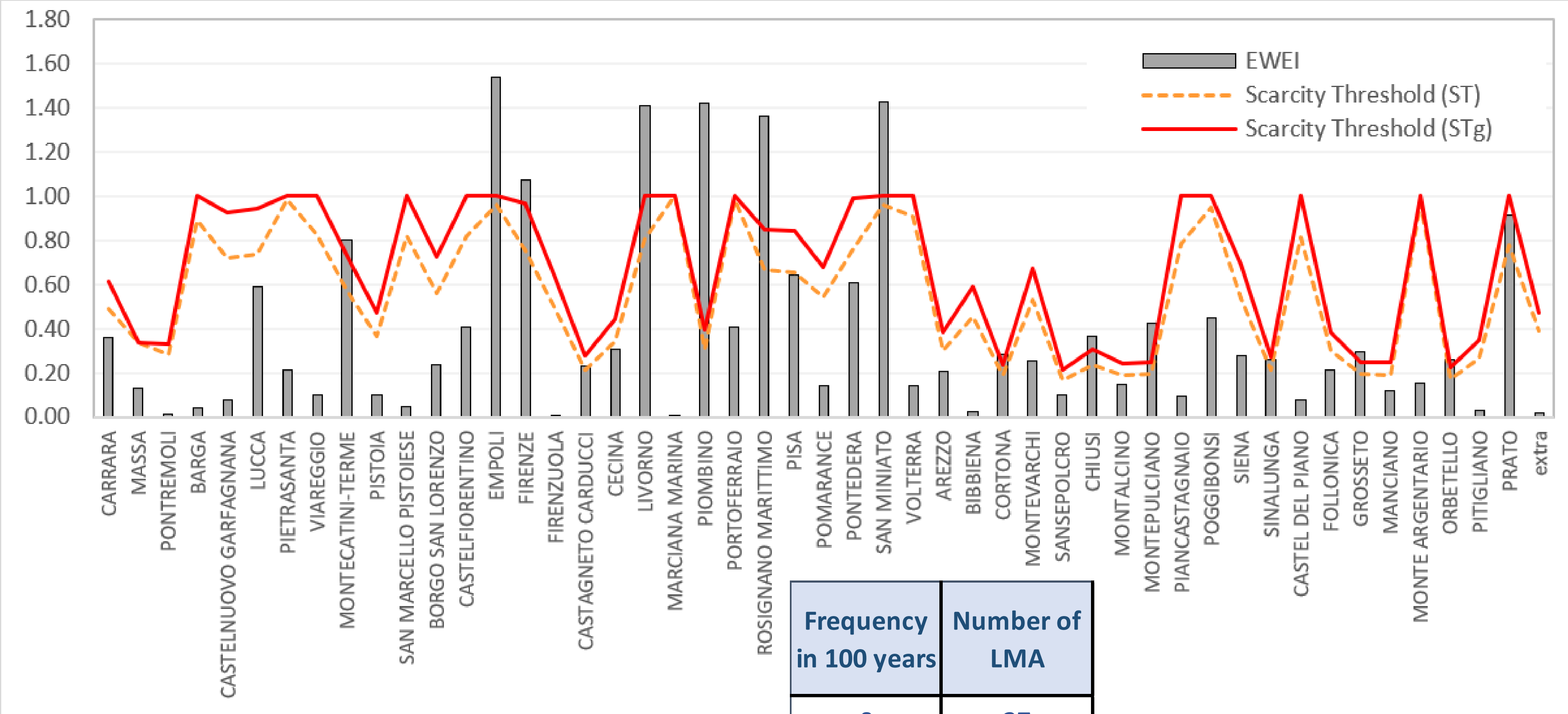
$$s.t.$$

$$\frac{(v_{blue}^{s} + v_{grey}^{s})^{T} \cdot L^{s} \cdot \hat{\phi} \cdot d}{FS^{s}} \leq ST_{g}^{s} \leq ST^{r} \quad , \quad \forall r$$

$$\phi^{s} \in [0,1] \quad , \quad \forall s \in \Gamma$$

where e is a (mn) vector of ones and Γ is the set of subregions with scarcity conditions.

Figure 3. Average EWEI, ST and STg by LMA

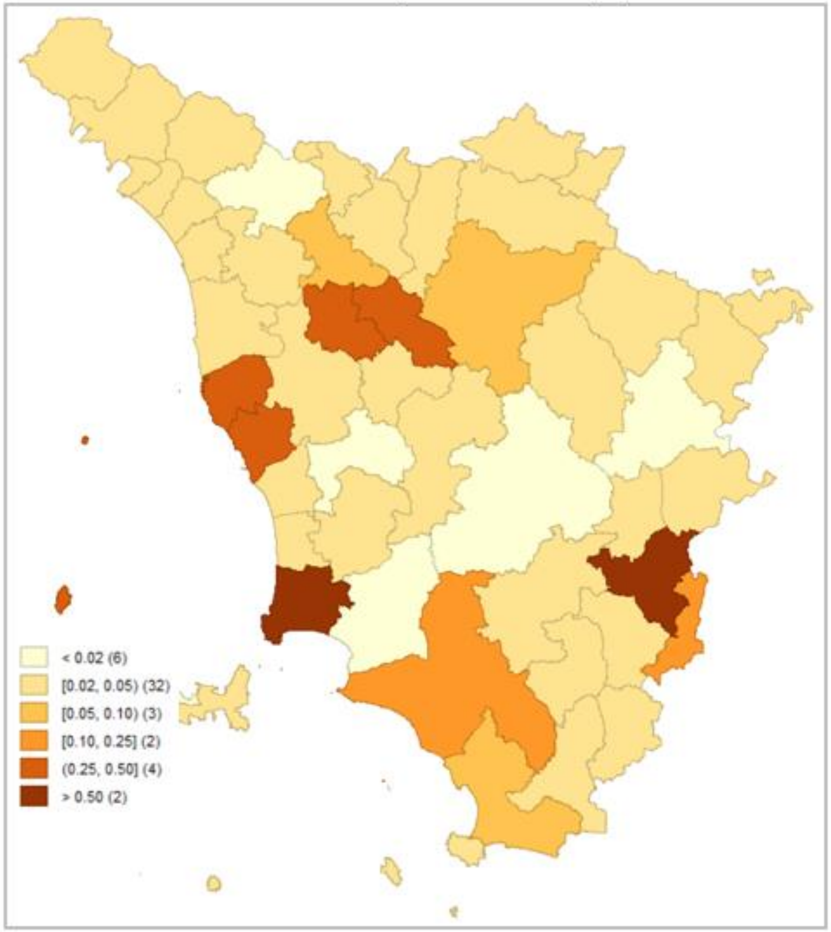


Source: own elaborations

Frequency in 100 years	Number of LMA
0	27
1 - 24	8
25-49	6
50-74	2
75-99	1
100	5

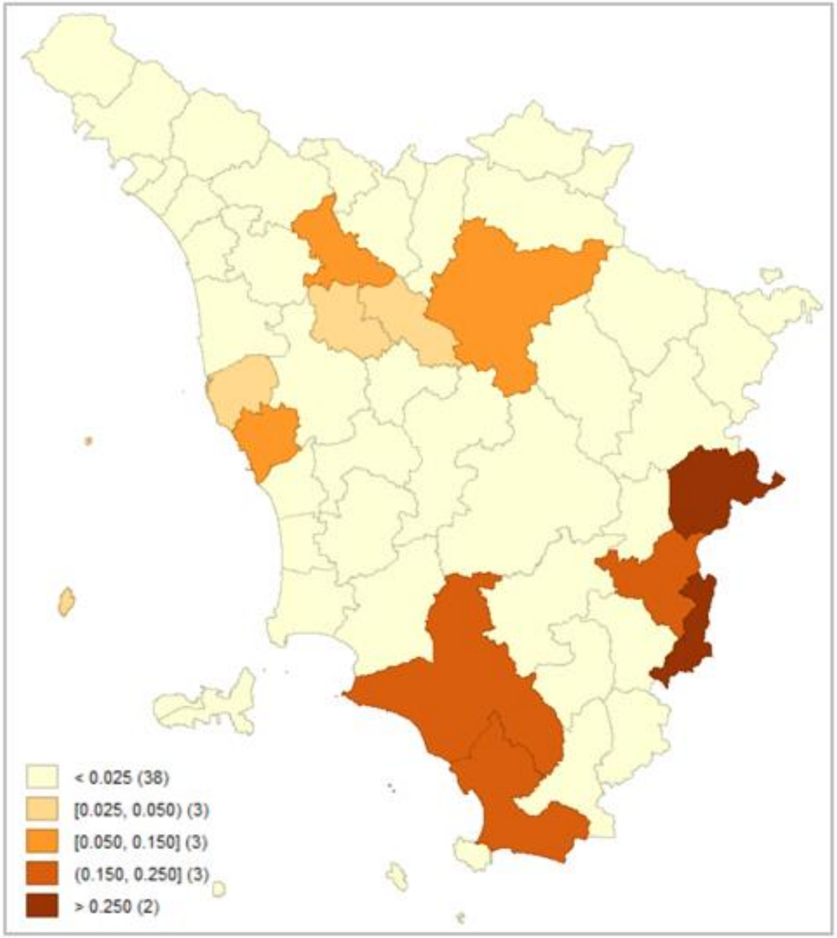
Cost of hydro-economic equilibrium

Base scenario - Value of Output decrease (%)



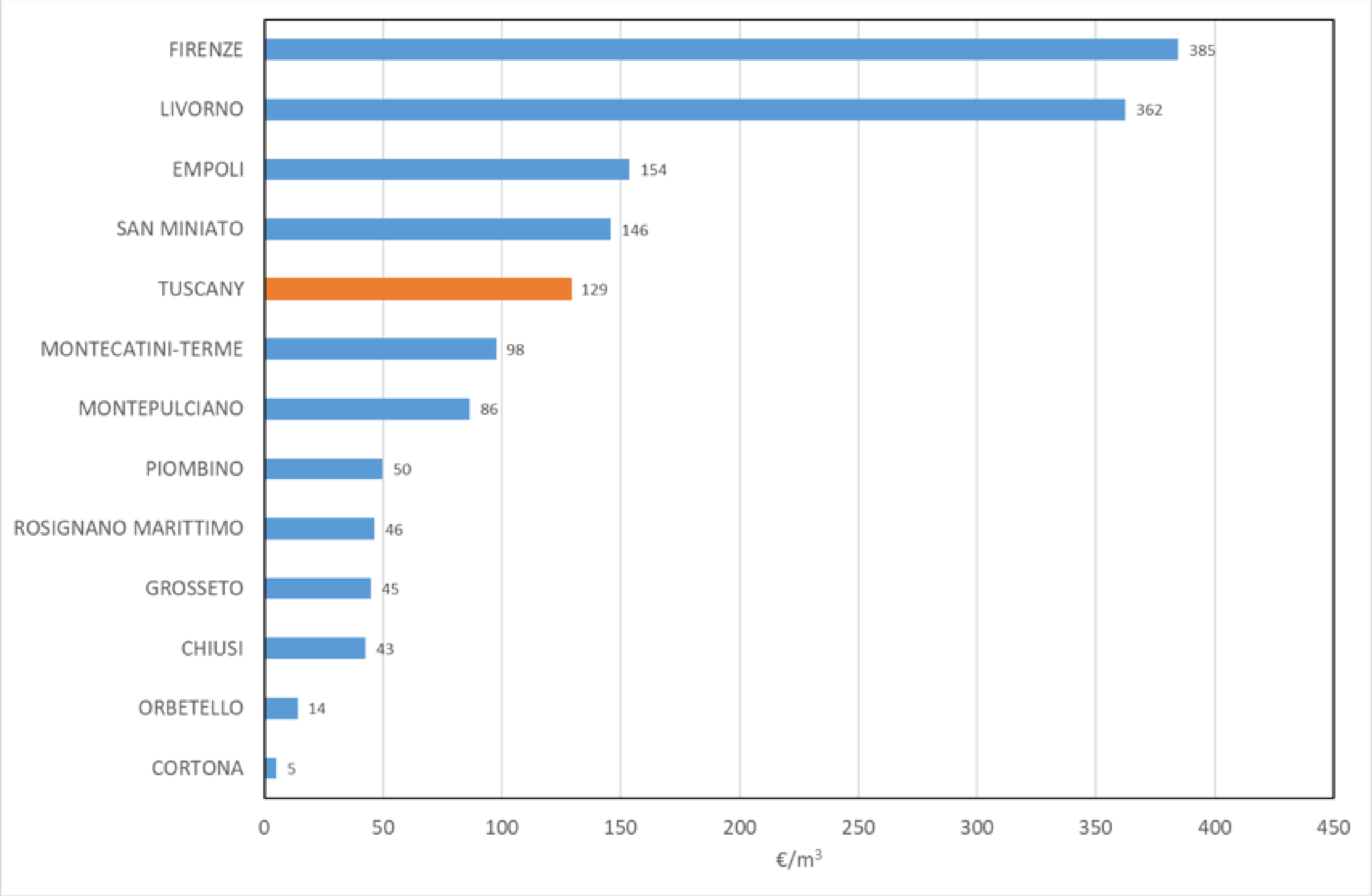
Source: own elaborations

Impact of climate change on HEEC (% variation)



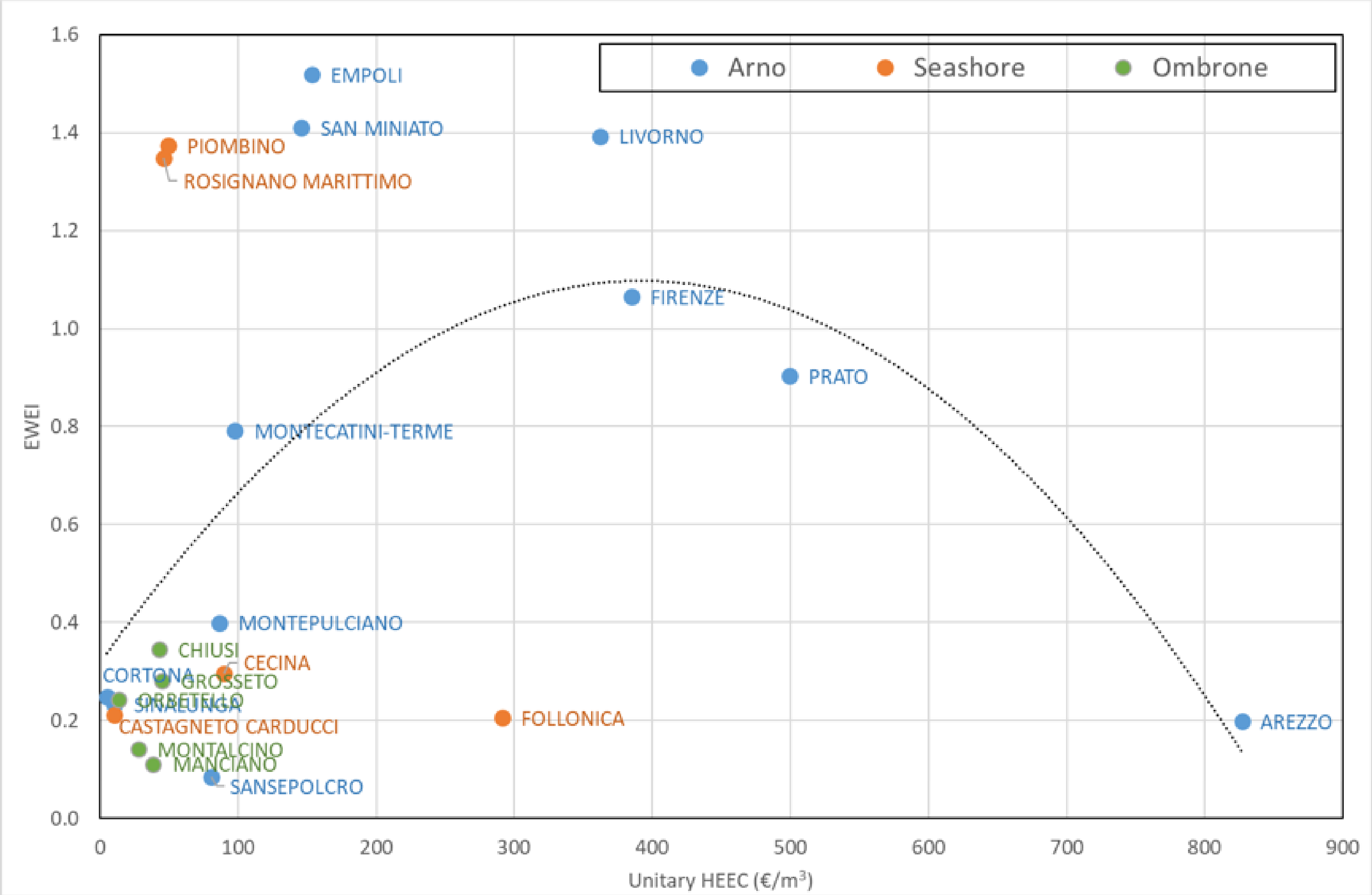
Source: own elaborations

Figure 7
Unitary cost of hydroeconomic equilibrium
€/m³ – Different LMA and regional Average



Source: own elaborations

Figure 8
Water exploitation at the subregional level
Average unitary HEEC (€/m3) and EWEI by LMA and hydrological basin



Source: own elaborations

Concluding remarks

- Going beyond average annual values
- The scale of analysis is essential
- The management of water *scarcity* is a local issue (but inter regional interdependencies matter)
- HEEC concept useful in assessing investments for water regulations
- Looking forward: including ecosystem services in the model