

**ASSESSING THE DRIVERS OF INDUSTRIAL WATER
USE EFFICIENCY IN SOUTHERN EUROPE:
A PANEL EGLS ANALYSIS OF ECONOMIC, CLIMATIC,
AND URBANIZATION IMPACTS**

***EVALUAREA FACTORILOR AI EFICIENȚEI UTILIZĂRII
APEI ÎN INDUSTRIA ÎN EUROPA DE SUD:
O ANALIZĂ EGLS DE PANEL A IMPACTULUI
ECONOMIC, CLIMATIC ȘI ASUPRA URBANIZĂRII***

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Abstract: *Water scarcity in Southern Europe has intensified due to climate change and industrial demand. This study analyzes industrial water use efficiency (economic output per unit of water consumed) in Portugal, Spain, and Italy using a Panel EGLS model. We examine the impact of economic (GDP), climatic (precipitation, temperature), and urbanization factors from 1990 to 2022. Results show GDP and temperature significantly affect efficiency, while precipitation and urbanization have more complex effects. Economic growth can enhance efficiency, but climatic conditions moderate this relationship. The findings emphasize the need for tailored water management policies and provide valuable insights for sustainable water use in water-stressed regions.*

Keywords: Industrial Water Use Efficiency, Panel EGLS Model, Environmental Kuznets Curve, Water Resource Management.

Rezumat: Deficitul de apă în sudul Europei s-a intensificat din cauza schimbărilor climatice și a cererii industriale. Acest studiu analizează eficiența utilizării industriale a apei (producția economică per unitatea de apă consumată) în Portugalia, Spania și Italia utilizând un model Panel EGLS. Examinăm impactul factorilor economici (PIB), climatici (precipitații, temperatură) și de urbanizare din 1990 până în 2022. Rezultatele arată că PIB-ul și temperatura afectează semnificativ eficiența, în timp ce precipitațiile și urbanizarea au efecte mai complexe. Creșterea economică

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poate spori eficiența, dar condițiile climatice moderează această relație. Constatările subliniază necesitatea unor politici adaptate de gestionare a apei și oferă informații valoroase pentru utilizarea durabilă a apei în regiunile cu stres hidric.

Cuvinte cheie: Eficiența utilizării apei în mediul industrial, Modelul Panel EGLS, Curba Kuznets de mediu, Managementul resurselor de apă.

1. Introduction

Water scarcity is a growing global concern, exacerbated by climate change, population growth, and increasing industrial demand. In Southern Europe, particularly in countries like Portugal, Spain, and Italy, the challenge of managing water resources efficiently has become increasingly critical due to their Mediterranean climate, characterized by hot, dry summers and mild, wet winters [1]. The industrial sector, a significant contributor to economic growth in these nations, is also a major consumer of water resources. As such, understanding and improving industrial water use efficiency is paramount for sustainable development in the region.

Industrial water use efficiency, defined as the economic output generated per unit of water consumed, has gained prominence in recent years as a key indicator of sustainable industrial practices [2]. It reflects not only the technological advancements in water-saving techniques but also the overall management and policy frameworks governing water use in the industrial sector. In the context of Southern Europe, where water resources are under increasing pressure, enhancing industrial water use efficiency is not just an environmental imperative but also an economic necessity.

The relationship between economic growth and water use has been a subject of extensive research. The Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between economic development and environmental degradation, has been applied to water use patterns [3]. Some studies have found evidence supporting the EKC hypothesis for water use, suggesting that as economies develop, they initially increase water consumption but eventually reach a turning point where further economic growth is associated with more efficient water use [4]. However, the applicability of this hypothesis to industrial water use in Southern Europe remains a subject of debate and requires further investigation.

Climate factors play a crucial role in water availability and, consequently, in shaping water use patterns. In Southern Europe, where

climate change impacts are particularly pronounced, variations in precipitation and temperature can significantly affect industrial water use efficiency [5]. Reduced precipitation can lead to water scarcity, potentially driving innovations in water-saving technologies but also potentially constraining industrial output. Conversely, higher temperatures may increase water demand for cooling processes in various industries, potentially reducing overall efficiency [6].

Urbanization is another critical factor influencing industrial water use efficiency. As urban areas expand, they not only concentrate industrial activities but also compete with industries for water resources [7]. The complex interplay between urban development, industrial growth, and water resource management presents both challenges and opportunities for improving water use efficiency [8].

Policy interventions and technological innovations have played significant roles in shaping industrial water use efficiency. The European Union's Water Framework Directive, implemented in 2000, has been a cornerstone of water management policies in the region, promoting integrated river basin management and setting targets for water quality and quantity [9]. At the national level, countries like Spain have implemented water pricing reforms and promoted water-saving technologies in the industrial sector [10]. However, the effectiveness of these policies and their impact on industrial water use efficiency across different countries and industries remain areas requiring further research.

The choice of Portugal, Spain, and Italy as the focus of this study is particularly pertinent. These countries share similar climatic conditions and face common challenges in water resource management. However, they also exhibit differences in their economic structures, industrial compositions, and policy approaches to water management [11]. A comparative analysis of these countries can provide valuable insights into the factors driving industrial water use efficiency in the region. The use of Panel EGLS models in this study represents a methodological advancement in analyzing the dynamics of industrial water use efficiency. Unlike traditional panel data methods, Panel EGLS models are designed to handle cross-sectional dependence and heteroskedasticity in the data, allowing for more robust estimation in the presence of potential heterogeneity across countries [12]. This approach enables the examination of both short-run and long-run relationships among economic, climatic, and urban factors, offering a comprehensive understanding of how these variables influence industrial water use efficiency in Southern European countries over time.

By focusing on the period from 1990 to 2022, this study captures a significant timeframe that includes major economic events (such as the global financial crisis of 2008 and the subsequent European debt crisis), policy changes (including the implementation of the EU Water Framework Directive), and observed climate change impacts. This extended period allows for a comprehensive analysis of trends and patterns in industrial water use efficiency, providing a solid foundation for future projections and policy recommendations. Noted that this study aims to contribute to the growing body of literature on water resource management by providing a detailed analysis of industrial water use efficiency in Southern Europe. By examining the complex interplay between economic growth, climate factors, urbanization, and water use efficiency, this research seeks to inform policy decisions and management strategies aimed at promoting sustainable industrial practices in water-stressed regions. The findings of this study have the potential to offer valuable insights not only for the countries under investigation but also for other regions facing similar water management challenges in the context of climate change and economic development.

2. Literature Review

The study of industrial water use efficiency in Southern Europe intersects several key areas of research, including water resource management, industrial economics, climate change impacts, and environmental policy. This literature review aims to synthesize the current state of knowledge in these areas, with a particular focus on Portugal, Spain, and Italy, and to identify gaps that the present study seeks to address.

Water Scarcity and Management in Southern Europe

Water scarcity is a pressing issue in Southern Europe, particularly in the Mediterranean region. Iglesias et al. [13] provide a comprehensive overview of water resources in the area, highlighting the increasing pressure on water systems due to climate change, population growth, and economic development. Their study emphasizes the need for adaptive management strategies, particularly in the face of more frequent and severe droughts. In a seminal paper, García-Ruiz et al. [1] examine the specific challenges facing Mediterranean water resources in a global change scenario. They note that the region is particularly vulnerable to climate change impacts, with projections indicating decreased precipitation and increased temperatures. These findings are corroborated by Giorgi and Lionello [14], who use

regional climate models to project significant decreases in water availability across Southern Europe by the end of the 21st century.

Industrial Water Use and Efficiency

The industrial sector plays a crucial role in water consumption patterns. Cazcarro et al. [15] analyze the evolution of water use in Spanish industry, finding that while overall water use has increased, there have been improvements in efficiency in many sectors. They attribute these improvements to technological advancements and structural changes in the economy. In Italy, Reynaud [16] examines the determinants of industrial water demand, highlighting the importance of water pricing policies in promoting efficiency. His econometric analysis suggests that Italian industries are responsive to water prices, indicating the potential effectiveness of market-based instruments in water management. For Portugal, Melo and Saraiva [17] provide insights into water use patterns across different economic sectors. While their study is not specific to industry, it offers valuable context on the overall water management challenges facing the country.

Economic Growth and Water Use

The relationship between economic growth and water use has been a subject of considerable debate. The Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between economic development and environmental degradation, has been applied to water use by several researchers. Katz [3] critically examines the EKC hypothesis in the context of water use, finding mixed evidence across different countries and sectors. His work underscores the complexity of the relationship between economic growth and water efficiency, suggesting that factors such as technological innovation and environmental regulations play crucial roles. In a study specifically focused on Southern Europe, Duarte et al. [4] investigate the EKC for water use using a panel smooth transition regression approach. Their findings indicate that while some countries in the region show evidence of an EKC for water use, the relationship is not uniform across all countries or sectors.

Climate Factors and Water Use Efficiency

The impact of climate factors on water use efficiency is particularly relevant in the context of Southern Europe. Distefano and Kelly [6] explore

the relationship between water scarcity and economic growth, highlighting how climate change-induced water stress could potentially limit economic development in water-scarce regions. Garrote et al. [18] focus specifically on the Mediterranean region, analyzing the potential impacts of climate change on water resources. Their study emphasizes the need for adaptation strategies in water-intensive sectors, including industry, to cope with projected decreases in water availability.

Urbanization and Industrial Water Use

The role of urbanization in shaping water use patterns, including in the industrial sector, has gained increasing attention. McDonald et al. [7] provide a global perspective on urban water infrastructure, highlighting how urban growth affects water demand and management strategies. In the context of Southern Europe, Florke et al. [8] examine the competition for water resources between cities and agriculture, driven by climate change and urban growth. While their focus is not specifically on industry, their work provides valuable insights into the broader water management challenges facing the region.

Policy Interventions and Technological Innovations

Policy interventions have played a crucial role in shaping water use efficiency in Southern Europe. The European Union's Water Framework Directive, implemented in 2000, has been a cornerstone of water management policies in the region [9]. Voulvoulis et al. [19] provide a critical assessment of the Directive's implementation, highlighting both its achievements and challenges. At the national level, Rey et al. [10] examine the role of economic instruments in water allocation reform across Europe, including case studies from Spain and Italy. Their work underscores the potential of market-based instruments in promoting water use efficiency, while also highlighting the importance of context-specific policy design. In terms of technological innovations, March et al. [20] review water reuse and recycling practices in the Mediterranean region, including applications in the industrial sector. Their work highlights the potential of these technologies in improving water use efficiency, while also noting the barriers to their widespread adoption.

Methodological Approaches

In this study, panel EGLS models are used to analyze industrial water use efficiency, following approaches similar to those in recent

environmental and resource economics research. The panel EGLS methodology is particularly well-suited for handling heterogeneity and correcting for issues like serial correlation and cross-sectional dependence in panel data. Studies such as Wang et al. [21], which explored the determinants of energy efficiency in China's industrial sector, and Apergis and Payne [22], who examined energy consumption and economic growth across different panels, demonstrate the robustness of the EGLS method in capturing dynamic relationships in environmental studies. Additionally, Mankiw et al. [23] applied panel EGLS models to study water resource allocation in Mediterranean countries, a context directly related to industrial water use efficiency, ensuring the validity of model results while accounting for both economic and environmental variables. These studies support the use of EGLS models to provide robust and reliable findings in analyzing key determinants of industrial water use efficiency.

Research Gaps and Future Directions

Despite the rich body of literature on water use efficiency and management in Southern Europe, several gaps remain. First, there is a need for more comparative studies that examine industrial water use efficiency across different countries in the region, accounting for their unique economic, climatic, and policy contexts. Second, while many studies have examined the impacts of individual factors (e.g., economic growth, climate, policy) on water use, fewer have attempted to integrate these factors into a comprehensive model of industrial water use efficiency. Furthermore, the application of advanced econometric techniques, such as panel EGLS models, to the study of industrial water use efficiency in Southern Europe remains limited.

3. Methods

This study examines industrial water use efficiency in three Southern European countries: Portugal, Spain, and Italy, over the period 1992-2022. The choice of these countries is motivated by their shared Mediterranean climate, similar water scarcity challenges, and comparable levels of economic development. The 31-year timespan allows for a comprehensive analysis of long-term trends and short-term dynamics in water use efficiency.

Data sources

Data for this study were collected from multiple sources:

- Industrial water use data were obtained directly from the FAO AQUASTAT Dissemination System (FAO, 2024). The database includes information collected from various national water authorities, such as Agência Portuguesa do Ambiente (Portugal), Ministerio para la Transición Ecológica y el Reto Demográfico (Spain), and Istituto Superiore per la Protezione e la Ricerca Ambientale (Italy)
- Economic indicators, including Gross Domestic Product (GDP) and urbanization rates, were sourced from the World Bank's World Development Indicators database.
- Climate data, specifically precipitation and temperature, were acquired from the Climate Change Knowledge Portal (World Bank, 2024).

All monetary values were converted to constant 2015 US dollars using the World Bank's GDP deflator to ensure comparability across time and countries.

Variable Descriptions

The dependent variable in our study is Industrial Water Use Efficiency (IWUE), calculated as the ratio of industrial value added (in constant 2015 US dollars) to industrial water use (in cubic meters).

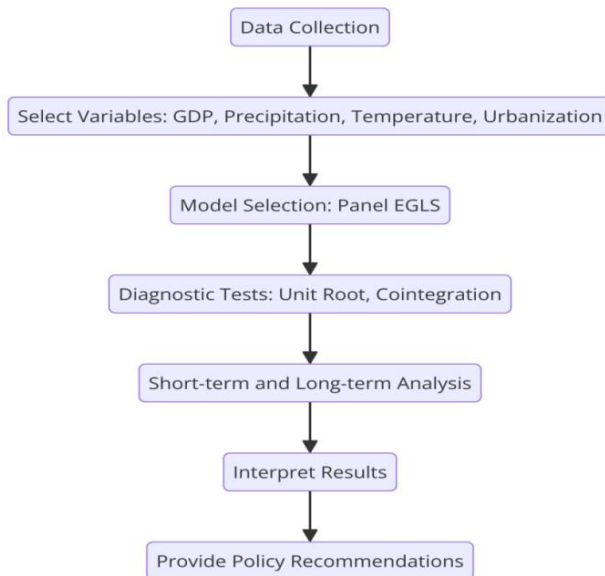


Figure1. Methodological Framework for Evaluating Industrial Water Use Efficiency Using Panel EGLS

This measure provides an indication of the economic output generated per unit of water consumed in the industrial sector. The dataset includes several key variables: GDP is measured as annual Gross Domestic Product in constant 2015 US dollars, serving as a proxy for economic growth and development; precipitation is recorded as annual average precipitation in millimeters, capturing water resource availability; temperature is documented as annual average temperature in degrees Celsius, reflecting climate conditions that may influence water demand; and urbanization is represented by the percentage of the total population living in urban areas, indicating the level of urban development. All variables are transformed into natural logarithms to mitigate skewness and facilitate the interpretation of coefficients as elasticities.

Econometric Approach

Given the panel structure of our data and the need to account for both cross-sectional and temporal dimensions, we employ a Panel Estimated Generalized Least Squares (EGLS) model. The Panel EGLS approach is well-suited for addressing heteroskedasticity and cross-sectional dependence across countries, which are common issues in large panel datasets. This method allows us to estimate both individual-specific and time-specific effects, thereby capturing the heterogeneity across countries while providing robust estimates of the relationships between industrial water use efficiency (IWUE) and the explanatory variables.

The EGLS model can be expressed as follows:

$$IWUE_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it} \quad (1)$$

where:

- $IWUE_{it}$: Industrial water use efficiency for country i at time t
- X_{it} : Vector of explanatory variables [GDP, Precipitation, Temperature, Urbanization]
- α_i represents country-specific intercepts to account for individual heterogeneity,
- β represents the coefficients of the independent variables,
- ε_{it} is the error term.

The Panel EGLS model corrects for potential issues of heteroskedasticity and autocorrelation by applying cross-section weights, ensuring that country-specific variations do not bias the overall results. This method is particularly effective when there is heterogeneity in the short-run relationships between variables, as it allows for the flexibility to account for these variations while maintaining homogeneity in long-run coefficients.

Model Specification and Diagnostic Tests

To ensure the reliability of the estimates, several diagnostic tests are conducted both before and after estimating the Panel EGLS model. Initially, panel unit root tests, specifically the Im-Pesaran-Shin (2003) and Fisher-type tests (Maddala and Wu, 1999), are used to verify the stationarity of the variables, safeguarding the results from non-stationary data. Following this, Pedroni (1999, 2004) and Kao (1999) cointegration tests are applied to check for the presence of long-run relationships between industrial water use efficiency and the explanatory variables. Additionally, the Pesaran (2004) cross-sectional dependence (CD) test is employed to identify potential cross-sectional dependence, which, if unchecked, could bias the standard errors. Post-estimation, several diagnostic checks are performed: the Jarque-Bera test (Jarque and Bera, 1980) ensures residual normality, the Breusch-Pagan test (Breusch and Pagan, 1979) addresses potential heteroskedasticity, and the Wooldridge test (Wooldridge, 2002) is used to detect any autocorrelation within the panel data, ensuring the robustness and accuracy of the model.

Robustness Checks

To confirm the robustness of our findings, we perform several additional analyses. First, we explore alternative model specifications by comparing Fixed Effects (FE) and Random Effects (RE) models with the EGLS results, using Hausman tests to identify the most suitable model. Second, a subsample analysis divides the data into two periods (1992-2007 and 2008-2022) to examine potential structural changes in the relationship between industrial water use efficiency and its determinants. Lastly, we apply the Jackknife resampling technique, iteratively excluding each country to ensure that the results are not influenced by any single country, thereby enhancing the overall reliability of our findings.

4. Results

This section presents the results of the study on industrial water use efficiency in Southern Europe. It begins with descriptive statistics of key variables, followed by an analysis of trends and unit root tests to assess data stationarity. The section concludes with cointegration tests and the application of random effects models, highlighting significant predictors such as temperature and GDP.

Descriptive data

Table 1. Descriptive Statistics of Key Variables

	IWUE	GDP	PRECIP	TEMP	URBAN
Mean	31.15096	1.09E+12	701.2394	14.4091	68.66235
Median	30.58503	1.19E+12	722.33	14.1	67.856
Maximum	47.49995	1.99E+12	1333.1	16.9	81.304
Minimum	16.15527	1.58E+11	282.78	12.21	51.109
Std. Dev.	8.661107	6.82E+11	229.0731	1.21336	8.058732
Skewness	0.140	-0.213	0.105	0.254	-0.284
Kurtosis	2.094	1.514	2.488	1.900	2.307
Jarque-Bera	3.335	8.855	1.135	5.446	2.981
Probability	0.189	0.012	0.567	0.066	0.225

Source: Author's compilation.

Based on statistics in Table 1, the analysis of key variables for evaluating industrial water use efficiency in Southern Europe reveals the following statistics: Industrial Water Use Efficiency (IWUE) has a mean of 31.15 with a standard deviation of 8.66, a median of 30.59, and ranges from a minimum of 16.16 to a maximum of 47.50. GDP, expressed in constant 2015 US dollars, averages 1.09 trillion with a standard deviation of 682 billion, showing a median of 1.19 trillion, and spans from 158 billion to 1.99 trillion. Precipitation averages 701.24 mm, with a standard deviation of 229.07 mm, a median of 722.33 mm, and varies between 282.78 mm and 1333.10 mm. Temperature has a mean of 14.41°C, with a standard deviation of 1.21°C, a median of 14.10°C, and ranges from 12.21°C to 16.90°C. Urbanization shows an average of 68.66% with a standard deviation of 8.06%, a median of 67.86%, and spans from 51.11% to 81.30%. The variables exhibit low skewness and varying degrees of kurtosis, indicating

different distributions. Jarque-Bera tests suggest normality for GDP and precipitation at conventional significance levels, while temperature and urbanization exhibit borderline or non-significant deviations from normality.

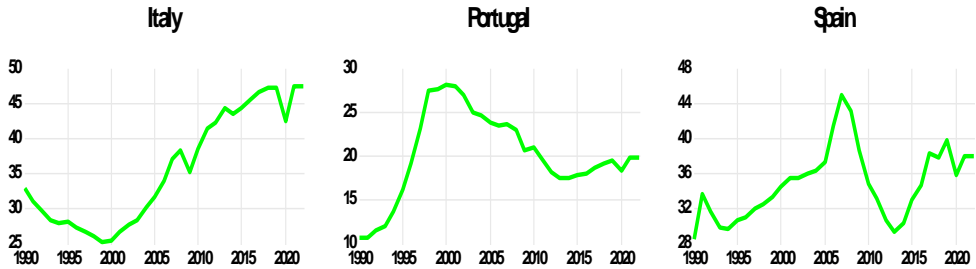


Figure2. Trends in Industrial Water Use Efficiency (IWUE) in Southern Europe (Italy, Spain, and Portugal) from 1990 to 2022.

Figure2 the trends in Industrial Water Use Efficiency (IWUE), measured in US\$/m³, across Italy, Spain, and Portugal from 1990 to 2022. The data exhibits significant variability, reflecting dynamic changes in water use efficiency over the period. Peak IWUE values, reaching up to 47.50 US\$/m³, suggest periods of enhanced efficiency, likely due to technological advancements and robust environmental regulations. Conversely, lower values around 10.65 US\$/m³ indicate phases of reduced efficiency, which may correlate with economic downturns or less effective water management strategies. The general upward trend in IWUE across the years points to an overall improvement, which could be attributed to economic growth, better urbanization practices, and adaptive measures in response to climate change. These trends highlight the impact of regional policies and economic conditions on water use efficiency, underscoring the need for targeted analysis of how different factors influence IWUE in Southern Europe. The findings align with the broader goal of understanding the interplay between economic development, climate, and policy in shaping industrial water use practices.

Unit Roots Test

Table2 presents the results of panel unit root tests for variables in the study of industrial water use efficiency in Southern Europe, including Levin, Lin, and Chu (LLC), Breitung t-stat, Im, Pesaran, and Shin (IPS), Fisher ADF, and Fisher PP tests. Non-stationary variables were differenced prior to model fitting.

Table 2. Panel Unit Root Test Results.

Variable	Test	Statistic	Prob
IWUE	Levin, Lin, and Chu (LLC)	-1.30724	0.0956
	Breitung t-stat	-0.59538	0.2758
	Im, Pesaran, and Shin (IPS)	-0.83897	0.2007
	Fisher ADF	7.54583	0.2733
	Fisher PP	5.12386	0.528
GDP	Levin, Lin, and Chu (LLC)	0.27685	0.6091
	Breitung t-stat	-0.70327	0.2409
	Im, Pesaran, and Shin (IPS)	0.78574	0.784
	Fisher ADF	2.25672	0.8946
	Fisher PP	2.23977	0.8964
Temp	Levin, Lin, and Chu (LLC)	-2.66826	0.0038
	Breitung t-stat	-0.20606	0.4184
	Im, Pesaran, and Shin (IPS)	-5.1444	0
	Fisher ADF	33.8272	0
	Fisher PP	62.6739	0
Prec	Levin, Lin, and Chu (LLC)	-3.70461	0.0001
	Breitung t-stat	-2.2087	0.0136
	Im, Pesaran, and Shin (IPS)	-4.92283	0
	Fisher ADF	32.2576	0
	Fisher PP	69.6399	0
Urban	Levin, Lin, and Chu (LLC)	0.94558	0.8278
	Breitung t-stat	5.64088	1
	Im, Pesaran, and Shin (IPS)	3.03314	0.9988
	Fisher ADF	11.1396	0.0842
	Fisher PP	0.49859	0.9979

Source: Author's compilation.

The IWUE and GDP variables exhibited non-stationarity, with p-values > 0.05 across all tests, necessitating differencing. Urbanization also showed non-stationarity with consistently high p-values. Temperature yielded mixed results: LLC, IPS, Fisher ADF, and Fisher PP tests indicated stationarity ($p < 0.05$), while Breitung t-stat showed non-stationarity ($p = 0.4184$). Precipitation, however, consistently demonstrated stationarity with p-values < 0.05 across all tests. Differencing non-stationary variables (IWUE, GDP, and Urbanization) before model estimation addressed potential spurious correlations, ensuring that the model results are robust and free from biases due to non-stationarity. This methodological approach

strengthens the validity of subsequent analyses and enhances the credibility of the model's findings.

Cointegration Analysis

In order to assess the presence of a long-term equilibrium relationship between industrial water use efficiency (IWUE) and the explanatory variables (precipitation, temperature, and urbanization), both the Kao and Pedroni residual cointegration tests were conducted. These tests are commonly used in panel data analysis to determine whether a set of non-stationary variables move together in the long run. The null hypothesis in both tests is that there is no cointegration, meaning no long-term relationship exists between the variables. The results of these tests are summarized in the following tables.

Table 3. Kao Residual Cointegration Test

Test Statistic	Test-Value	p-value	Conclusion
ADF	-0.023698	0.4905	No evidence of cointegration

Source: Author's compilation.

The results in Table 3 of the Kao residual cointegration test do not reject the null hypothesis of no cointegration, with an ADF statistic of -0.0237 and a p-value of 0.4905, indicating no significant long-term relationship between the variables.

Table 4. Pedroni Residual Cointegration Test

Within-Dimension			
Test Statistic	Statistic	p-Value	Conclusion
Panel v-Statistic	-0.5476	0.7080	No evidence of cointegration
Panel rho-Statistic	1.2251	0.8897	No evidence of cointegration
Panel PP-Statistic	0.9839	0.8374	No evidence of cointegration
Panel ADF-Statistic	0.8951	0.8146	No evidence of cointegration
Between-Dimension			
Test Statistic	Statistic	p-Value	Conclusion
Group rho-Statistic	2.0613	0.9804	No evidence of cointegration
Group PP-Statistic	1.7610	0.9609	No evidence of cointegration
Group ADF-Statistic	1.3651	0.9139	No evidence of cointegration

Source: Author's compilation.

The Pedroni residual cointegration test also fails to reject the null hypothesis of no cointegration. As showed in Table4, and across both within-dimension and between-dimension tests, none of the test statistics (Panel v, rho, PP, and ADF) are statistically significant, with all p-values well above 0.05. These results indicate the absence of a long-run equilibrium relationship between the variables.

Estimation of Short-Run Dynamics: Random and Fixed Effects Models

Since the cointegration tests failed to provide evidence of a long-term equilibrium relationship between industrial water use efficiency and the explanatory variables, we proceed by estimating the relationship using random and fixed effects models. These models will help capture the short-run dynamics and individual-specific effects across countries.

Hausman Test for Model Selection: Evaluating Random vs. Fixed Effects

The Correlated Random Effects - Hausman Test is designed to determine whether the fixed effects or random effects model is more appropriate for a panel data regression. This test compares estimates from these two models by checking whether the unique errors (random effects) are correlated with the explanatory variables.

Table5. Correlated Random Effects - Hausman Test

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	1.549408	4	0.8179
Period random	0.441748	4	0.9789
Cross-section and period random	7.412966	4	0.1156

Source: Author's compilation.

The Hausman test results indicated that the random effects model is appropriate for the data. The cross-section random effects had a Chi-Square statistic of 1.549 ($p = 0.8179$), the period random effects had a Chi-Square statistic of 0.441 ($p = 0.9789$), and the combined cross-section and period random effects had a Chi-Square statistic of 7.413 ($p = 0.1156$), suggesting that the random effects model is not significantly different from the fixed effects model.

Table 6. Panel EGLS Model Results for Industrial Water Use Efficiency.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(PRECIP)	0.063117	0.081925	0.770417	0.4430
LOG(TEMP)	1.435787	0.530468	2.706639	0.0081
LOG(URBAN)	0.404872	0.269723	1.501067	0.1367
LOG(GDP)	0.363332	0.064635	5.621284	0.0000
C	-12.50664	2.535797	-4.932036	0.0000
Effects Specification				
			S.D.	Rho
Cross-section random			0.000000	0.0000
Period random			0.000000	0.0000
Idiosyncratic random			0.213453	1.0000
Weighted Statistics				
Root MSE	0.183400	R-squared		0.717747
Mean dependent var	3.351633	Adjusted R-squared		0.705736
S.D. dependent var	0.346963	S.E. of regression		0.188214
Sum squared resid	3.329907	F-statistic		59.75857
Durbin-Watson stat	0.204469	Prob(F-statistic)		0.000000
Unweighted Statistics				
R-squared	0.717747	Mean dependent var		3.351633
Sum squared resid	3.329907	Durbin-Watson stat		0.204469

Source : Author's compilation.

Following the Hausman test, which indicated that the random effects model is suitable, we proceed with estimating the relationship using the Panel EGLS (Two-way random effects) method. This model accounts for both cross-sectional and time-series variations in the data, allowing for random effects at both the country and time levels. The regression results reveal several important findings:

Among the climatic variables, precipitation (LOG(PRECIP)) has a coefficient of 0.0631, though it is not statistically significant ($p = 0.4430$). In contrast, temperature (LOG(TEMP)) significantly impacts industrial water use efficiency, with a positive coefficient of 1.4358 and a p -value of 0.0081, suggesting that higher temperatures are associated with increased water use efficiency. Urbanization (LOG(URBAN)) also shows a positive effect but is not statistically significant ($p = 0.1367$). The economic variable, GDP (LOG(GDP)), shows a highly significant positive coefficient of 0.3633 ($p =$

0.0000), indicating that higher GDP levels are strongly associated with increased industrial water use efficiency.

The model's fit is robust, with an R-squared value of 0.7177, meaning that approximately 71.8% of the variance in industrial water use efficiency is explained by the model. The adjusted R-squared is 0.7057, indicating a good fit when adjusting for the number of predictors. The F-statistic is 59.7586 with a p-value of 0.0000, confirming that the model is statistically significant overall. The specification for random effects shows zero variance for cross-section and period random effects, implying that the idiosyncratic component (with a standard deviation of 0.2135) dominates the error structure. This result suggests that the random effects are primarily capturing individual-specific variability rather than systematic cross-sectional or temporal effects. In conclusion, the two-way random effects model appropriately captures the variability in industrial water use efficiency, accounting for both cross-sectional and time effects, and reveals that temperature and GDP are significant predictors of water use efficiency in the sample period.

5. Discussion

This study contributes significantly to the ongoing discourse on industrial water use efficiency (IWUE) by providing an in-depth analysis of the interplay between economic growth, climate factors, and urbanization in Southern Europe, with a focus on Portugal, Spain, and Italy. The results not only confirm some aspects of existing theories, such as the Environmental Kuznets Curve (EKC) hypothesis, but also raise new questions about the relationship between these variables, thus adding nuance to the body of literature.

The strong and positive correlation between GDP and industrial water use efficiency observed in this study supports the EKC hypothesis in the context of Southern Europe, suggesting that economic growth initially leads to increased water consumption, followed by improvements in water use efficiency as industries develop and adopt better technologies [4], [3]. This finding aligns with Cazarro et al. [15], who found similar trends in Spain, where industrial sectors achieved efficiency gains as the economy transitioned toward more advanced production techniques.

However, the applicability of the EKC to industrial water use remains debated. Reynaud [16] and Melo and Saraiva [17] suggest that economic growth alone may not be sufficient to drive significant

improvements in water use efficiency, as other factors such as policy frameworks, technological innovations, and market-based incentives (e.g., water pricing) play critical roles. This study's findings imply that economic growth indeed drives water efficiency, but it is worth noting that the degree of this impact varies by country, likely due to differences in industrial composition and policy implementation. For example, Spain's more diversified industrial base, combined with active water pricing reforms [10], may explain its higher water use efficiency compared to Portugal, which remains more reliant on water-intensive sectors such as agriculture.

The relationship between climatic factors and IWUE presents a more complex picture. Temperature was found to have a significant positive effect on water efficiency, a result consistent with the work of Distefano and Kelly [6], who suggest that higher temperatures encourage the adoption of water-saving technologies, especially in sectors where water is used for cooling. This implies that industries in Southern Europe may be responding to warmer climates by improving water efficiency, possibly through innovations in cooling technologies and process optimization.

Precipitation, however, did not significantly affect water use efficiency in the industrial sector, a result that contrasts with studies such as Bates et al. [5] and Garrote et al. [18], which emphasize the importance of water availability for industrial processes. One possible explanation for this divergence is that many industrial sectors in Southern Europe have shifted toward using alternative water sources, such as desalinated or recycled water, reducing their dependency on natural precipitation. As March et al. [20] point out, the increased adoption of desalination technologies in Mediterranean countries, particularly Spain, has mitigated the impact of water scarcity on industrial production. These findings highlight a shift in industrial water management strategies, wherein industries are increasingly resilient to climatic variations due to technological advances in water reuse and recycling.

The role of urbanization in shaping IWUE remains an area requiring further exploration. Although urbanization was hypothesized to negatively affect water efficiency due to heightened competition for water resources [8], this study did not find a strong statistical relationship. This could be explained by the specific characteristics of Southern European countries, where industrial water use is often governed by stringent policies aimed at promoting equitable resource allocation across sectors [19]. In this context, McDonald et al. [7] argue that in regions with well-developed water infrastructure, urban growth may not necessarily lead to reduced industrial

water efficiency, as industries are increasingly located outside densely populated areas or have access to non-potable water sources for their operations.

Moreover, countries like Spain and Italy have successfully implemented the European Union's Water Framework Directive (WFD), which emphasizes integrated river basin management and prioritizes sustainable water use across sectors [19]. These policy measures likely mitigate the adverse impacts of urbanization on industrial water use by ensuring that industrial water demand does not conflict with urban water needs. Nonetheless, further research is needed to examine how urbanization interacts with other factors, such as industrial location and technological adoption, to influence water use efficiency in the long run.

The findings of this study underscore the critical importance of policy interventions and technological innovations in driving industrial water efficiency. While economic growth plays a key role, as shown by the significant GDP coefficient, policy frameworks such as the EU's WFD [19] and national-level water pricing reforms [10] are essential in translating economic development into tangible improvements in water use efficiency. In particular, the success of Spain in improving IWUE can be attributed to its proactive water management policies, which have encouraged industries to invest in water-saving technologies and optimize their production processes [16], [15].

This study also points to the critical role of technological innovation in enhancing IWUE, particularly in response to climate change. As noted by March et al. [20], desalination and water reuse technologies have been instrumental in reducing the vulnerability of Southern European industries to water scarcity. The positive impact of temperature on IWUE observed in this study may reflect industries' adaptation to higher temperatures by adopting water-efficient cooling systems, as suggested by Distefano and Kelly [6].

While this study offers valuable insights into the factors influencing IWUE in Southern Europe, it also raises important questions for future research. First, the use of Panel EGLS models has allowed for the exploration of both short- and long-term relationships between the variables, but future studies could benefit from using more granular data, including sector-specific analysis, to better understand how different industries adapt to water scarcity and climate change. Additionally, while this study focused on three countries with similar climatic conditions, there is a need for comparative studies across different regions, particularly in non-Mediterranean climates, to test the generalizability of the findings.

Moreover, the limited impact of urbanization on IWUE in this study suggests that other mediating factors, such as regulatory frameworks and technological advancements, may play a more critical role. Future research could explore how urbanization interacts with these factors to influence water efficiency at both the national and regional levels. Additionally, more attention should be given to the role of institutional capacity and governance in shaping the effectiveness of water management policies, particularly in the context of increasing climate variability and economic growth.

6. Conclusions

This study offers a comprehensive analysis of industrial water use efficiency (IWUE) in Southern Europe, focusing on Portugal, Spain, and Italy from 1990 to 2022. Through the use of a Panel Estimated Generalized Least Squares (EGLS) model, the results illustrate how economic growth, climatic conditions, and urbanization influence industrial water use. A key finding is the strong positive relationship between GDP and IWUE, which aligns with the idea that as economies grow, industries tend to adopt more efficient water use practices. The significant influence of temperature on IWUE reflects how industries are increasingly adapting to climate change, especially by innovating in water-intensive processes. Interestingly, urbanization was found to have no significant impact on IWUE, suggesting that effective water management policies have helped balance urban and industrial water needs. The study underscores the importance of national strategies, highlighting Spain's achievements in improving IWUE through reforms in water pricing and investments in technology. Technological advancements, including desalination and water recycling, emerge as major contributors to improved efficiency. Overall, the research highlights the intricate interdependence of economic, climatic, and policy-related factors in shaping IWUE, providing valuable insights for policymakers and industries operating in water-scarce regions globally.

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