



A fuzzy-DEA water sustainability index: an application in European Union water risk hotspots

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Abstract

The current global freshwater crisis threatens the present and future supply of water as a resource for humans. The scarcity of drinking water and the dependence of the food industry on water-intensive supply chains require the urgent development of strategies to analyze and guarantee the water sustainability of countries. This study proposes a fuzzy-data envelopment analysis composite index that measures, from a benchmarking approach, water sustainability by simultaneously considering capacity and resilience, and captures the uncertainty associated with time series variations in three scenarios: pessimistic, indifferent and optimistic. We present and apply an index based on five indicators of capacity and five indicators of resilience in ten European Union countries water risk hotspots. The results in terms of capacity presented a higher variability due to the strong growth in the exploitation of water resources in Greece, Spain, France, Italy and Portugal. The most sustainable countries in terms of capacity were Bulgaria and Estonia in a pessimistic and an indifferent scenario and France and Bulgaria in an optimistic scenario. In terms of resilience, Belgium and Portugal were the most sustainable countries. When considering capacity and resilience together, some countries such as Bulgaria and Estonia lost positions in the ranking, with Belgium occupying the first position. Some countries, such as Bulgaria, could see the sustainability of their water resources compromised in a scenario of economic development if they do not improve their governance and water productivity constraints.

Keywords Fuzzy · Data envelopment analysis · Optimization · Water sustainability · Composite indicators · Resilience

1 Introduction

About 70% of the earth's surface is covered with water, yet only 2.5% of this is freshwater is drinking water (The Economist Intelligence Unit Limited, 2019). This small proportion of freshwater is the driver of human health, the global economy, and the well-being of societies in the broadest sense (Rani et al., 2021). Unfortunately, despite the importance of

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water to humans, the world has failed to sustainably manage its water resources (Ribeiro et al., 2021). Over the past century, available freshwater resources have come under increasing pressure as withdrawal rates have increased almost sixfold. In 2014, the average global availability of renewable freshwater fell to less than 6000 cubic meters per person per year, a steep drop of about 40% since the 1970s. In addition, freshwater resources are unevenly distributed around the world and suffer from strong seasonality, and as global water demand continues to grow (about 1% per year) available resources are further depleted (The Economist Intelligence Unit Limited, 2019).

The global water crisis has caused many companies to face serious risks related to freshwater scarcity in their operations and supply chains (González et al., 2020). The concern for sustainable water management in supply chains has motivated the proliferation of a large number of works concerned with proposing innovative techniques aimed at improving the efficiency of water management (Mozafari & Zabihi, 2020; Saif & Almansoori, 2014) or analyzing the effect of water on the supply chain in specific sectors, such as the coal (Pan et al., 2012) or fish industry (Tabrizi et al., 2018). In this regard, the great interest generated by some initiatives to measure the anthropogenic impact on water resources, such as the water footprint analysis is noteworthy. The concept of water footprint has been developed to measure water use in relation to people's consumption. The water footprint of a country is defined as the volume of water needed for the production of goods and services consumed by the country's inhabitants (Chapagain & Hoekstra, 2004).

Hoekstra and Mekonnen (2012) identified and quantified a particularly important water footprint in the food sector and concluded some truly alarming figures in a context of freshwater crisis. About 85% of humanity's water footprint is related to the consumption of agricultural products; 10% is related to industrial products and only 5% to domestic water consumption. These findings make the lack/absence of water sustainability a particularly sensitive issue, as it directly affects human survival. The human impact on water resources and water scarcity justifies the fact that water sustainability is one of the main concerns of governments and international institutions. With the prospect of billions of people facing serious water scarcity problems and associated food shortages, the management of water as a resource requires urgent strategic action. Currently two billion people live in countries with large water deficits and by 2030, 700 million people are expected to be displaced by intense water scarcity (de Castro-Pardo et al., 2021).

Concern for sustainability, and in particular water sustainability, is the focus of major international policies (Dabbous & Tarhini, 2021), both at the global and European levels (de Castro-Pardo et al., 2022; Martí & Puertas, 2022; Puertas et al., 2022). Water plays a key role in the framework of the 2030 Agenda. Specifically, water has a dedicated target in the Sustainable Development Goals (SDG 6). SDG-6 is based on "Ensure availability and sustainable management of water and sanitation for all". This target broadly covers all aspects of both the water cycle and sanitation systems, and its scope is designed in a cross-cutting manner, so that it can contribute to the scope of other SDGs, notably environment, health, economy and education. It is easy to conclude that without due attention to the development of the water sector in general, it will be impossible to achieve most of the SDGs. The Water Framework Directive in Europe has also defined its overall objective in ensuring the sustainability of water resources, through six strategic axes: Public Participation, River Basin Districts, General Studies of the Districts, Protected Areas, Cost Recovery and Measurement Programs (European Union, 2020). In the framework of international water resources policies, decision-making processes are particularly complex due to the multidimensional nature of sustainability, the transboundary nature of water management, the inherent

conflictuality of water use and the large number of stakeholders involved. In this context, it is crucial to have tools such as composite indicators (CIs) that provide a rigorous and near complete measure of sustainability, that in addition, permits the integration of multiple decision-makers in the decision-making processes (Fernández et al., 2020; Ruiz et al., 2011, 2020; Martín & Salinas, 2022; Guaita et al., 2022). Scores provided by CIs represent some very rich and complete information that involves characteristics or dimensions very diverse simultaneously. This is particularly interesting when the phenomenon to assess is complex as water sustainability (Zermeño et al., 2020). A CI permits comparisons using as a reference the information contained in a set of different indicators, thus they show in a simple way—single number—the rich information contained in several variables (Rodríguez et al., 2018). So, the interpretation and evaluation is easier (Rodríguez et al., 2017).

Numerous studies have proposed different water sustainability indicators, such as Cai et al. (2002), Sandoval-Solis et al. (2011), Linhoss and Ballweber (2015), Juwana et al. (2016) and Cervantes-Jiménez et al. (2020). Cai et al. (2002) used a distance-based mathematical programming model. They proposed a long-term CI based on six inter-year control variables: end of year water storage, available area of a crop, water distribution efficiency, water application efficiency, water drainage efficiency, salt discharge tax rate, and seven sustainability criteria: reliability, reversibility, vulnerability, environment, spatial equity, temporal equity, economic acceptability. Sandoval-Solis et al. (2011) used three indices to calculate a composite index of sustainable water management: resilience, reliability and vulnerability. Linhoss and Ballweber (2015) added three components of water sustainability: water resource, water demand and water policy dimensions, calculating weights with a stochastic approach. Juwana et al. (2016) considered three dimensions: water use, conservation, governance and policy to measure the sustainability of three water catchments in Indonesia. Cervantes-Jiménez et al. (2020) developed a sustainable water management index and applied it to measure the sustainability of 969 sub-basins in Mexico and considered the three traditional dimensions of sustainability: environmental, social, economic and also an institutional dimension. All these works considered associated elements that capture the quantity and quality of water resources in their analyses. However, only one of them has considered measurement uncertainty (Linhoss & Ballweber, 2015) and only Sandoval-Solis et al. (2011) considered the resilience component explicitly. The objective of this study is to propose a composite indicator, based on a Fuzzy-DEA model that considers the capacity of countries in terms of quality, quantity and accessibility of renewable water resources and their ecological, social and economic resilience, jointly: the water sustainability fuzzy index (WSFI). The novelty of the proposed indicator lies in the fact that it makes it possible to analyze, separately and jointly, the capacity of countries in terms of water and their ecological and social resilience, allows the uncertainty associated with the time series to be taken into account and provides results from three risk scenarios: pessimistic, indifferent and optimistic.

The paper is structured as follows. In the second section we provide a literature review on Fuzzy methods to the assessment of sustainability. In the third section we present the data and methodology used in the model development and its application in ten European Union water risk hotspot countries. The fourth section are dedicated to the presentation and discussion of the results of the research, and in the sixth section we provide some conclusions and recommendations.

2 The fuzzy approach to assess sustainability

Fuzzy sets were formulated by Zadeh (1965) and are based on the idea of incorporating a degree of membership of an element. Thus, if we assume that U means the entire set, classical set theory assumes that, given a subset A of U ($A \subset U$), then each element x is either a member of A ($x \in A$) or not a member of A ($x \notin A$). However, fuzzy theory is based on multi-valued logic. Fuzzy methods are particularly useful for solving complex and ill-defined problems such as measuring sustainability. The key element of fuzzy sets for measuring sustainability is the membership function. Fuzzy logic states that a membership function is a non-dichotomous set, in which there can be several degrees of membership between 0 and 1. The uncertainty of membership is not due to error or randomness, but can be caused by three concepts: (a) ambiguity, since a single concept may comprise more than one sub-concept (b) vagueness, due to boundaries that are not well defined and (c) generality, since the same concept applies to a variety of situations. The membership function of a fuzzy set can be defined as the way in which the degree of membership of a fuzzy x is determined and is the instrument to describe the imprecise characteristics of a fuzzy set (Mendoza & Prabhu, 2003).

The way of aggregating the different simple indices is a crucial element in the design of composite indicators and must be perfectly defined when working with fuzzy numbers. On the one hand, the relative importance of each simple index can be defined in advance or uncertainty can be incorporated to identify the relative weights. Shen et al. (2011) proposed two optimization models with fuzzy numbers and unknown weights to design composite indicators and applied them to measure the performance of a road safety policy in 25 European countries. The fuzzy approach was derived from a qualitative assessment of five indices that were transformed into symmetrical triangular fuzzy numbers. Mu et al. (2018) considered the same relative importance to assess the eco-efficiency of 55 dairy farms in Western Europe and measured uncertainty through fuzzy numbers that were modeled using α -cuts. Hatami-Marbini et al. (2013) used a Fuzzy Data Envelopment Analysis-BCC (named after Banker, Charnes and Cooper) (DEA-BCC) model to measure crisp and interval efficiencies in fuzzy environments. All these works used a Data Envelopment Analysis DEA-type optimization model using fuzzy numbers. Connectivity between the different elements of the model is also an important part of the aggregation process. All these papers used an optimization approach using a DEA-type model and fuzzy numbers. Andriantiat-saholiniaina et al. (2004) used fuzzy logic reasoning to evaluate sustainable development strategies, from a “Pressure–Status–Response” approach and performed a sensitivity analysis to identify the factors that contributed most importantly to sustainable development. Vinodh (2011) used a multi-grade fuzzy analysis collecting qualitative ratings using a Likert scale on 52 sustainability attributes. Bockstaller et al. (2017) used fuzzy decision trees to assess sustainability and applied this methodology in the agricultural sector. They also used a sensitivity analysis to validate the proposed model.

The complexity of the concept of water sustainability provides a wide range of possibilities for working with fuzzy methods. Agarwal and Singh (2022) used a fuzzy approach to evaluate the performance of textile wastewater treatment techniques. They integrated Fuzzy Delphi and fuzzy analytical hierarchy process (FAHP) to aggregate 38 sub-indicators on sustainability from existing studies and experts. Halkijevic et al. (2017) proposed a joint fuzzy logic/neural network model to assess the sustainability of the water supply in Croatia. Dadmand et al. (2020) and Pan et al. (2022) used different fuzzy optimization models for the sustainable allocation of water resources in water-scarcity conditions and to

balance agricultural and ecological water management, respectively. The former proposed robust fuzzy stochastic programming and the latter developed a multi-objective interval model. Fuzzy optimization methods can provide very comprehensive information for decision making (Mardani et al., 2016, 2019), as they provide comprehensive results that permit: (1) identifying conflicts and points of agreement, (2) presenting results under different risk scenarios (Mendoza & Prabhu, 2003) and (3) capturing uncertainty associated with missing data or data collected over long periods of time. Despite this, to date no fuzzy optimization model has been proposed to measure the sustainable development of countries in terms of water. The WSFI permits the measurement of the sustainability of countries in terms of water, captures the uncertainty associated with non-homogeneous time series, and provides information regarding three risk scenarios: pessimistic, indifferent and optimistic.

3 Methods

3.1 The benefit-of-the-doubt DEA approach

Data envelopment analysis was first proposed by Charnes et al. (1978). It consists of a mathematical programming methodology that measures the relative efficiency of a homogeneous set of decision making units (DMUs) as a function of multiple inputs and multiple outputs. Benefit-of-the-doubt (BoD) was quickly recognized as a very powerful optimization tool for modeling operational processes in terms of benchmarking, evaluation performance and decision making (Koronakos et al., 2021). The BoD approach originates from DEA in an imprecise information environment. In particular, it is based on the use of DEA analysis to evaluate a set of homogeneous production units, using input variables and output variables in an environment in which the weights associated with these variables are not known, nor is the form of the function relating these variables. The very name “*benefit of the doubt*” represents the essence of this type of model and emphasizes its ability to obtain the most appropriate weighting scheme for each decision unit performance benchmarking from the data available for each unit of analysis (Cherchye et al., 2011). A large number of works have already used this approach, with success, for the construction of composite indicators, such as Cherchye et al. (2007), Verbunt and Rogge (2018) and Guaita et al. (2020). The main difference with respect to traditional DEA models is that only the output variables are fixed, considering a single input dummy variable with a value equal to 1 for each unit of analysis.

In particular for the construction of composite indicators, the BoD-DEA approach identifies the relative importance to be assigned to each indicator to obtain the best performance in terms of benchmarking and uses an additive method to construct the composite indicator associated with each decisional unit. In this way, the BoD model places the performance of a decisional unit in relation to the rest of the DMUs and assigns the highest weights to the former indicators and the lowest to the latter, so that the model selects the most favorable set of weights for each unit of analysis.

The basic BoD-DEA models for constructing composite indicators can be defined according to Eqs. (1, 1.1. and 1.2.).

$$CI_c = \max_{w_{c,i}} \sum_{i=1}^m w_{c,i} I_{c,i} \quad (1)$$

s.t.

$$\sum_{i=1}^m w_{c,i} I_{j,i} \leq 1 \quad (1.1)$$

(n constraints, one for each decision making unit j).

$$w_{c,i} \geq 0 \quad (1.2)$$

(m constraints, one for each indicator i).

One of the main advantages of this approach for the construction of composite indicators lies in its ability to highlight excellent DMUs that stand out from the rest or, seen from another perspective, to identify DMUs that obtain the worst results and, therefore, make it possible to identify problems in advance.

3.2 The fuzzy DEA model for the WSFI

To deal with imprecision and vagueness in DEA-type models, fuzzy logic can be a very useful approach, capable of providing very complete results. Fuzzy-DEA models have the form of a fuzzy linear programming model with fuzzy coefficients in both the objective function and the constraints, so that sometimes some “fuzzy inequality” or “maximizing a fuzzy variable” operators are required. In this paper a simplified model using non-symmetric triangular fuzzy functions is proposed.

Definition (León et al., 2003). It is said that $\tilde{M}$ is an LR-fuzzy number, $\tilde{M} = (m^L, m^R, \alpha^L, \alpha^R)_{L,R}$, if its membership function takes the following form:

$$\mu_{\tilde{M}}(r) = \begin{cases} L\left(\frac{m^L - r}{\alpha^L}\right), & r \leq m^L \\ 1, & m^L \leq r \leq m^R \\ R\left(\frac{r - m^R}{\alpha^R}\right), & r \geq m^R \end{cases} \quad (2)$$

where the subset $[m^L, m^R]$ consists of the real numbers with the highest chance of realization, α^L is the left spread, α^R is the right spread, L and R are reference functions that form the left and right shapes of the fuzzy number, respectively.

Also, L and R satisfy the following conditions:

$$L, R : [0, +\infty) \rightarrow [0, 1],$$

$$L(x) = L(-x), \quad R(x) = R(-x),$$

$$L(0) = 1, \quad R(0) = 1$$

$L(x)$ and $R(x)$ are strictly decreasing and upper semi-continuous on $\text{supp}(M) = \{r : \mu_{\tilde{M}}(r) > 0\}$.

An LL fuzzy number is a triangular fuzzy number that can be defined as an LR fuzzy number where $L(x) = R(x)$ with $L(x) = \max(0, 1 - |x|)$.

Following the approach used by Shen et al. (2011) by incorporating a possibility level h to obtain the fuzzy best performing results, this paper proposes three crisp linear

programming models using triangular fuzzy indicators $\tilde{I}_{rj}$ that can be denoted with their center and spreads as $\tilde{I}_{rj} = (i_{rj}^C, \alpha_{rj}^L, \alpha_{rj}^R)$, $r = 1, \dots, s, j = 1, \dots, n$.

Following these assumptions, three models based on fuzzy time series (Singh, 2017; Song & Chissom, 1993) are proposed to construct a composite indicator that measures water sustainability considering the capacity of countries to provide sufficient water of sufficient quality and considering the resilience of the countries.

Model 1 permits the measurement of an indicator by considering only the indicators associated with capacity.

Model 1

$$CI_0 = \max \lambda_1^C \sum_{r=1}^s w_r^C (i_{r0}^C - (1-h) \alpha_{r0}^{LC}) + \lambda_2^C \sum_{r=1}^s w_r^C (i_{r0}^C + (1-h) \alpha_{r0}^{RC}) \quad (3)$$

s.t.

$$\sum_{r=1}^s w_r^C (i_{rj}^C - (1-h) \alpha_{rj}^{LC}) \leq 1, \quad j = 1, \dots, n. \quad (3.1)$$

$$\sum_{r=1}^s w_r^C (i_{rj}^C + (1-h) \alpha_{rj}^{RC}) \leq 1, \quad j = 1, \dots, n. \quad (3.2)$$

$$\sum_{r=1}^s w_r^C = 1 \quad (3.3.)$$

$$w_r^C \geq \delta_r^C \quad (3.4)$$

$$\lambda_1^C + \lambda_2^C = 1 \quad (3.5)$$

where CI_0 is the capacity indicator of country 0, w_r^C are the weights associated with each capacity indicator r , i_{rj}^C is the center of the fuzzy number representing the capacity indicator r of country j and is the mean value of all indicators included in a time series, α_{rj}^{LC} and α_{rj}^{RC} are the spreads to the left and right of country j 's indicator r , and represent the distance between the mean value of all the indicators included in a time series and the minimum indicator or between the mean value and the maximum value of the series, respectively. h is the possibility level that models the amplitude of the fuzzy number and takes values 0 and 1, so that when h is zero, the spread of the fuzzy number is not considered, only the central value. The parameters λ_1^C and λ_2^C adopt values between 0 and 1 and provide the results under three scenarios, optimistic, when $\lambda_1^C = 0$, pessimistic, when $\lambda_1^C = 1$ and indifferent, when $\lambda_1^C = \lambda_2^C$. Shen et al. (2011) and Mendoza and Pradhu (2003) used similar parameters to provide fuzzy solutions in these three situations.

The value of the parameter δ_r^C represents the minimum acceptable value for the weights of each indicator and represents the minimum relative importance that should be given to each indicator. The value of this parameter can be defined according to the decision-maker's experience or according to the results obtained in previous analyses, but it also allows a participatory approach to be included in the model, considering the assessments of a panel of experts.

Model 2 allows an indicator to be measured by considering only the indicators associated with resilience.

Model 2

$$RI_0 = \max \lambda_1^R \sum_{r=1}^s w_r^R (i_{r0}^R - (1-h) \alpha_{r0}^{IR}) + \lambda_2^R \sum_{r=1}^s w_r^R (i_{r0}^R + (1-h) \alpha_{r0}^{rR}) \quad (4)$$

s.t.

$$\sum_{r=1}^s w_r^R (i_{rj}^R - (1-h) \alpha_{rj}^{IR}) \leq 1, \quad j = 1, \dots, n \quad (4.1)$$

$$\sum_{r=1}^s w_r^R (i_{rj}^R + (1-h) \alpha_{rj}^{rR}) \leq 1, \quad j = 1, \dots, n. \quad (4.2.)$$

$$\sum_{r=1}^s w_r^R = 1 \quad (4.3)$$

$$w_r^R \geq \delta_r^R \quad (4.4)$$

$$\lambda_1^R + \lambda_2^R = 1 \quad (4.5)$$

Analogous to model 1, model 2 is constructed with analogous form and variables but only includes the resilience indicators, and allows the calculation of the resilience indicator RI_0 of country 0. Thus, the super-indices C have been replaced with super-indices R, in order to distinguish the variables associated with each type of approach; capacity and resilience.

Model 3 is based on models 1 and 2 and allows the WSFI to be calculated considering the capacity and resilience of the countries analyzed simultaneously. The parameters τ_1 and τ_2 permit modeling the relative weight of each approach for the calculation of the global index. Thus, when τ_1 is 0, the global index will only consider the indices associated with resilience. When τ_1 is 1, the global index will only consider the indices associated with capacity. When τ_1 takes values between 0 and 1, the global index will consider both approaches in the proportion determined by the analyst.

Model 3

$$WSFI_0 = \max \tau_1 CI_0 + \tau_2 RI_0 \quad (5)$$

s.t.

$$\sum_{r=1}^s w_r^C (i_{rj}^C - (1-h) \alpha_{rj}^{IC}) \leq 1, \quad j = 1, \dots, n. \quad (5.1)$$

$$\sum_{r=1}^s w_r^C (i_{rj}^C + (1-h) \alpha_{rj}^{rC}) \leq 1, \quad j = 1, \dots, n. \quad (5.2)$$

$$\sum_{r=1}^s w_r^R \left(i_{rj}^R - (1-h) \alpha_{rj}^{IR} \right) \leq 1, \quad j = 1, \dots, n. \quad (5.3)$$

$$\sum_{r=1}^s w_r^R \left(i_{rj}^R + (1-h) \alpha_{rj}^{IR} \right) \leq 1, \quad j = 1, \dots, n. \quad (5.4)$$

$$\sum_{r=1}^s w_r^C = 1 \quad (5.5)$$

$$\sum_{r=1}^s w_r^R = 1 \quad (5.6)$$

$$w_r^C \geq \delta_r^C \quad (5.7)$$

$$w_r^R \geq \delta_r^R \quad (5.8)$$

$$\lambda_1^C + \lambda_2^C = 1 \quad (5.9)$$

$$\lambda_1^R + \lambda_2^R = 1 \quad (5.10)$$

$$\tau_1 + \tau_2 = 1 \quad (5.11)$$

There are two main advantages of these models with respect to non-fuzzy models: they provide results in three risk scenarios, pessimistic, indifferent and optimistic in a simple way, and they permit the uncertainty of the time series to be taken into account. Obtaining results in risk scenarios can be very interesting to improve decision-making processes. On the one hand, it generates very rich, complete information about a problem, and, on the other hand, it permits identification of common areas between the valuations of several decision makers or between data collected from different years, sources, etc. On the other hand, when working with long time series, it is usual to work with uncertainty derived from the lack of data in intermediate positions, variations over time or other factors that affect the availability of data. The model provides results considering the path of each series and presents them in the form of intervals, which permits the presentation of results that gather the information contained in each series in a wide, flexible way.

4 Constructing the fuzzy water sustainability index

4.1 Indicators and data

The ability of countries to provide sufficient, safe water and citizens' access to these resources was captured through five indicators (1.1, 1.2, 1.3, 1.4, 1.5). The quantity and quality of water resources capture the essence of sustainability in terms of water and

virtually all water sustainability indicators measure these characteristics in some way. Cai et al. (2002), and Linhoss and Ballweber (2015) are just a couple of examples. On the other hand, access to water resources is present in most ICs measuring water sustainability and captures the essence of SDG-6. “Ensure availability and sustainable management of water and sanitation for all” (Millennium Ecosystem Assessment, 2005). This target broadly covers all aspects of both the water cycle and sanitation systems, and its scope is designed in a cross-cutting manner, so that it can contribute to the scope of other SDGs, especially environment, health, economy and education.

The five indicators linked to capacity are:

- 1.1 Renewable freshwater resources per inhabitant: indicates the availability of a country’s renewable freshwater resources.
- 1.2 Water exploitation index: provides a measure of how total water demand puts pressure on water resources (European Environment Agency, 2022); it is calculated as total annual average freshwater demand divided by long-term average freshwater resources.
- 1.3 Gross Nutrient balance per hectare of utilized agricultural area (UAA): presents a measure of water status. “The indicator provides an indication of the potential surplus of nitrogen (N) on agricultural land (kg N per ha per year)” (Eurostat, 2021). Some studies such as Jelić and Šimurina (2020), and Staes et al. (2018) have used it to measure water pollution.
- 1.4 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (%): It specifies the capacity of countries to provide renewable water resources. It is calculated as “the ratio between total freshwater withdrawn by all major sectors and total renewable freshwater resources, after taking into account environmental flow” (United Nations, 2021).
- 1.5 Proportion of the population using safely managed drinking water services (%): measures the availability and accessibility of drinking water for citizens in a country.

Resilience represents the capacity of systems to adapt to changing conditions. Folke (2016: 44) defined resilience as follows: “resilience is having the capacity to persist in the face of change, to continue to develop with ever changing environments”. To reflect the resilience of freshwater systems, three indicators related to the adaptive capacity of ecosystems and two indicators related to the adaptive capacity of societies were defined. The indicators included in the first group are associated with the fight against climate change (2.1.), watershed erosion (2.2.), aquifer depletion and the protection of freshwater aquatic ecosystems (2.3.). The indicators included in the second group are associated with good governance and are represented by a corruption perception index (2.4.) and water productivity (2.5.).

The five indicators linked to resilience are:

- 2.1 Greenhouse gas emissions: includes greenhouse gas emissions and represents a country’s contribution to climate change in absolute terms.
- 2.2 Estimated soil loss by water erosion: includes soil loss due to water erosion and areas affected by severe erosion. The indicator estimates soil loss due to water erosion processes (sheetwash, rain splash, and rills) for agricultural areas and natural grasslands (Eurostat, 2021).
- 2.3 Freshwater Key Biodiversity Areas: includes protected areas and key biodiversity areas (KBAs).

- 2.4 Corruption Perception Index: refers to citizens' perception of corruption in a country and is an indicator of good governance in countries (Transparency International, 2021).
- 2.5 Water productivity: water productivity indicates the amount of economic output produced per cubic meter of freshwater withdrawn. It serves as a measure of water use efficiency. Lower water productivity mainly means that the country's economic and industrial structure is water intensive. An economy that consumes less water would show relatively high water productivity.

The data used was collected from six international databases: Eurostat, the European Environmental Agency, United Nations, the European Commission-Joint Research Centre, Transparency International and the Organization for Economic Cooperation and Development. The data covers the period 2000–2019 and each one of them were identified as “more is better” (+) or “less is better” (–) indicators (Table 1).

The original indicators were normalized following a min–max scaling method. Then, the normalized scores are fuzzified, taking as the central value of the triangle the mean value of all the values of the series and calculating the right and left spreads, subtracting and adding the minimum and maximum indicator of each series to the mean value, respectively.

It is common to use symmetrical triangular fuzzy numbers, often for simplicity and often due to lack of information. The proposed model permits the identification of asymmetric triangular fuzzy numbers, which provides very useful information in decision-making processes since it incorporates a more realistic scenario approach than symmetric approximations.

4.2 Application, results and discussion

The proposed model was applied to ten of the EU countries identified as having the highest water risk by the Aqueduct Project of the World Resources Institute (WRI, 2021): Belgium, Bulgaria, Cyprus, Estonia, France, Greece, Italy, Luxembourg, Portugal and Spain. The Water Risk Atlas map analyzes current and future water risks across locations and involves physical risks quantity, physical risks quality and some issues regarding drinking and sanitation for the population. Table 2 describes the normalized scores of the minimum, the maximum and the mean of the time series, the left spread (α_l), and the right spread (α_r). A participatory component was incorporated into this application, incorporating the assessments of a panel of experts on the minimum importance for each indicator. In total, the assessments of 20 experts from academic, scientific and technical fields were collected through an online questionnaire during the months of June and July 2021. These minimum weights were calculated using a geometric mean between the ratings of the 20 experts and were incorporated into the models through constraints 3.4, 4.4, 5.7 and 5.8.

The application of model 1, which considers only indicators related to capacity, and the application of model 2, which considers only indicators related to resilience, provided the results presented in Table 3. The worst results for capacity were obtained by Cyprus, Portugal and Greece and the best results were obtained by France, Bulgaria and Estonia. However, the worst results in terms of resilience were for Cyprus, Italy and Spain and the best for Belgium, Portugal and Luxembourg (Tables 3, 4). It is interesting to draw attention to the robustness of the results associated with resilience. In 60% of the countries, the results

Table 1 Approaches, indicators and units, years of time series used, type of indicator and source

Dimension	Indicators and units	Years (available data)	Type	Source
Capacity	1.1. Renewable freshwater resources per inhabitant	2007–2017	+	Eurostat
	1.2. Water exploitation index (%)	2000–2017	–	European Environment Agency (EEA)
	1.3. Gross Nutrient Balance per hectare UAA (kg of nutrient per ha)	2010–2019	–	European Environment Agency (EEA)
	1.4. Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (%)	2000–2018	–	United Nations (SDG)
	1.5. Proportion of population using safely managed drinking water services (%)	2010–2018	+	United Nations (SDG)
Resilience	2.1. Greenhouse gas emissions (in CO ₂ equivalent) (tonnes per capita)	2000–2018	–	European Environment Agency (EEA)
	2.2. Estimated soil loss by water erosion by land cover type (tonnes per hectare)	2000, 2010, 2016	–	European Commission—Joint Research Centre (JRC)
	2.3. Average proportion of Freshwater Key Biodiversity Areas (KBAs) covered by protected areas (%)	2000–2019	+	United Nations (SDG)
	2.4. Corruption Perception Index (score: worst 0–100 best)	2012–2019	+	Transparency International
	2.5. Water productivity [Euro per cubic meter (Euro: chain-linked volumes, reference year 2010, at 2010 exchange rates)]	2000–2018	+	Organization for economic co-operation and development (OECD)

Table 2 Normalized scores that represent the minimum, maximum and the mean of time series, the left spread (α_L), and the right spread (α_R)

Capacity	1.1					1.2					1.3					1.4					1.5					
	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	
Bel-gum	0.0989	0.1661	0.1403	0.0414	0.0258	0.6874	0.9603	0.9101	0.2226	0.0502	0.2495	0.3755	0.3052	0.0556	0.0703	0.0000	0.0000	0.5668	0.0749	0.0922	0.7156	0.7447	0.7298	0.0142	0.0150	
Bul-garia	0.4933	1.0000	0.9148	0.4216	0.0852	1.0000	1.0000	1.0000	0.0000	0.0000	0.9956	1.0000	0.9993	0.0036	0.0007	0.1645	0.4191	0.3113	0.1468	0.1078	0.8251	0.8402	0.8335	0.0085	0.0067	
Cyprus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4919	0.6590	0.5668	0.0749	0.0922	0.7156	0.7447	0.7298	0.0142	0.0150	
Estonia	1.0000	1.0000	1.0000	0.0000	0.0000	0.5417	0.9258	0.8059	0.2642	0.1200	0.8903	0.9720	0.9229	0.0326	0.0492	0.7050	0.7720	0.7343	0.0294	0.0377	0.8532	0.8737	0.8638	0.0106	0.0099	
France	0.0753	0.6145	0.2301	0.1548	0.3844	0.8242	0.9751	0.9419	0.1177	0.0333	0.5586	1.0000	0.8852	0.3266	0.1148	0.5391	0.6951	0.6116	0.0725	0.0835	0.9898	1.0007	0.9981	0.0083	0.0026	
Greece	0.5509	0.5509	0.5509	0.0000	0.0000	0.0000	0.6782	0.5277	0.5277	0.1505	0.6789	0.8341	0.7798	0.1009	0.0543	0.6292	0.7688	0.6894	0.0602	0.0794	0.5480	0.7258	0.6468	0.0988	0.0791	
Italy	0.5672	0.5672	0.5672	0.0000	0.0000	0.0000	0.7075	0.9003	0.8366	0.0604	0.7078	0.0000	0.7714	0.5422	0.0604	0.0708	0.4201	0.6272	0.5053	0.0604	0.0708	0.9848	1.0000	0.9935	0.0604	0.0708
Luxem-burg	0.1135	0.7228	0.4182	0.3046	0.3046	0.8601	0.9924	0.9604	0.1003	0.0319	0.3147	0.3935	0.3596	0.0449	0.0339	1.0000	1.0000	1.0000	0.0000	0.0000	0.7124	0.7388	0.7281	0.0158	0.0107	
Portu-gal	0.1195	1.0000	0.3860	0.2665	0.6140	0.6484	0.9149	0.8307	0.1823	0.0843	0.6992	0.9018	0.8420	0.1428	0.0598	0.7006	0.7905	0.7428	0.0423	0.0476	0.0000	0.0000	0.0000	0.0000	0.0000	
Spain	0.0418	0.4121	0.1400	0.0982	0.2721	0.2566	0.8289	0.6939	0.4373	0.1349	0.6493	1.0000	0.8951	0.2458	0.1049	0.1347	0.3671	0.2212	0.0865	0.1458	0.9138	0.9253	0.9195	0.0056	0.0059	
Resil- ience	2.1					2.2					2.3					2.4					2.5					
	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	Min	Max	Mean	α_l	α_r	
Bel-gum	0.6963	0.7394	0.7154	0.0191	0.0240	0.8850	0.8952	0.8911	0.0062	0.0041	0.9400	0.9565	0.9455	0.0055	0.0109	0.8182	0.9000	0.8572	0.0390	0.0428	0.0652	0.0883	0.0749	0.0097	0.0135	
Bul-garia	0.8667	0.9239	0.8928	0.0261	0.0311	0.7080	0.7476	0.7296	0.0217	0.0179	0.9646	0.9681	0.9668	0.0022	0.0013	0.0000	0.1136	0.0173	0.0173	0.0963	0.0000	0.0000	0.0000	0.0000	0.0000	
Cyprus	0.7107	0.7730	0.7331	0.0224	0.0399	0.6903	0.7143	0.7044	0.0142	0.0099	0.0000	0.0000	0.0000	0.0000	0.0000	0.3500	0.6818	0.4718	0.1218	0.2100	0.0630	0.1077	0.0793	0.0163	0.0284	
Estonia	0.5053	0.5381	0.5173	0.0120	0.0208	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.6364	0.8378	0.7172	0.0809	0.1206	0.0020	0.0036	0.0028	0.0007	0.0009	
France	0.9264	1.0000	0.9567	0.0303	0.0433	0.8053	0.8286	0.8165	0.0112	0.0121	0.5677	0.6209	0.5915	0.0238	0.0294	0.6591	0.7955	0.7201	0.0610	0.0754	0.0664	0.0764	0.0704	0.0040	0.0060	
Greece	0.7797	0.8370	0.8001	0.0205	0.0369	0.5752	0.5825	0.5796	0.0043	0.0030	0.8900	0.8932	0.8920	0.0020	0.0012	0.0000	0.1351	0.0661	0.0661	0.0690	0.0096	0.0158	0.0119	0.0023	0.0039	
Italy	0.8983	0.9922	0.9339	0.0604	0.0708	0.0000	0.0000	0.0000	0.0604	0.0708	0.8447	0.8478	0.8462	0.0604	0.0708	0.0000	0.2703	0.1420	0.0604	0.0708	0.0345	0.0345	0.0345	0.0604	0.0708	
Luxem-burg	0.0000	0.0000	0.0000	0.0000	0.0000	0.7168	0.7238	0.7197	0.0029	0.0041	0.0098	0.0098	0.0098	0.0000	0.0000	1.0000	1.0000	1.0000	0.0000	0.0000	1.0000	1.0000	1.0000	0.0000	0.0000	
Portu-gal	1.0000	1.0000	1.0000	0.0000	0.0000	0.7168	0.7524	0.7325	0.0156	0.0199	0.4816	0.4833	0.4824	0.0008	0.0009	0.5128	0.6136	0.5393	0.0265	0.0743	0.0281	0.0281	0.0281	0.0000	0.0000	
Spain	0.9266	0.9609	0.9429	0.0164	0.0180	0.5752	0.6095	0.5956	0.0203	0.0140	0.1991	0.2077	0.2056	0.0064	0.0022	0.3590	0.6591	0.4580	0.0990	0.2011	0.0248	0.0286	0.0262	0.0014	0.0025	

Table 3 Scores of the FWSI for the analyzed countries by pessimistic, indifferent and optimistic scenarios when only Capacity is assessed and when only Resilience is assessed

Belgium	Capacity			Resilience		
	0.6835	0.7151	0.7308	0.8098	0.8202	0.8202
Bulgaria	0.8409	0.9045	0.9151	0.7444	0.7444	0.7444
Cyprus	0.4752	0.4908	0.5087	0.5423	0.5423	0.5423
Estonia	0.8409	0.9045	0.9151	0.7444	0.7444	0.7444
France	0.7849	0.8571	0.9248	0.7688	0.7688	0.7688
Greece	0.5789	0.7051	0.7678	0.6787	0.6886	0.6886
Italy	0.7862	0.8397	0.9024	0.6151	0.6756	0.6756
Luxembourg	0.7856	0.8362	0.8786	0.7803	0.7806	0.7806
Portugal	0.5462	0.6798	0.8441	0.7809	0.7809	0.7809
Spain	0.6677	0.7395	0.8469	0.6813	0.6813	0.6813

Table 4 Rank of the analyzed countries by pessimistic, indifferent and optimistic scenarios when only Capacity is assessed and when only Resilience is assessed

Rank capacity				Rank resilience			
1°	Bulgaria	Bulgaria	France	1°	Belgium	Belgium	Belgium
2°	Estonia	Estonia	Bulgaria	2°	Portugal	Portugal	Portugal
3°	Italy	France	Estonia	3°	Luxembourg	Luxembourg	Luxembourg
4°	Luxembourg	Italy	Italy	4°	France	France	France
5°	France	Luxembourg	Luxembourg	5°	Bulgaria	Bulgaria	Bulgaria
6°	Belgium	Spain	Spain	6°	Estonia	Estonia	Estonia
7°	Spain	Belgium	Portugal	7°	Spain	Greece	Greece
8°	Greece	Greece	Greece	8°	Greece	Spain	Spain
9°	Portugal	Portugal	Belgium	9°	Italy	Italy	Italy
10°	Cyprus	Cyprus	Cyprus	10°	Cyprus	Cyprus	Cyprus

in the optimistic and indifferent scenarios were the same as in a pessimistic scenario. In the rest of the countries, the results of the optimistic scenario coincided with those of the indifferent scenario. This is due to the reduced time variability in these indicators, mainly in countries such as Bulgaria, Cyprus and Estonia.

By applying model 3, simultaneously considering capacity and resilience, modeling their importance through the parameters τ_1 and τ_2 , the results described in Table 5 were obtained.

Figure 1 shows the triangular fuzzy charts that represent the results of the composite indicator when the capacity and resilience indicators are considered together and with different degrees of importance. These charts provide information on changes in the series, propensity to obtain optimistic, pessimistic or indifferent results, the indicator scores of each country in terms of benchmarking and the strengths/weaknesses with respect to the capacity and resilience of each country. The width of the triangle indicates changes in the series, either due to strong trends, irregular scores throughout the series or anomalous data. The triangles with the largest amplitude are observed when the capacity indicators are weighted more heavily and correspond to Spain, Portugal, France, Italy and Greece. This is mainly due to the strong, constant growth of the water

Table 5 Rank of the analyzed countries by pessimistic, indifferent and optimistic scenarios when Capacity and Resilience weights are 0.25 and 0.75 respectively and Capacity and Resilience weights are 0.75 and 0.25 respectively

	Rank C/R 0.5					Rank C 0.25 R 0.75					Rank C 0.75 R 0.25				
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	1°	2°	3°	4°	5°
1°	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium	Belgium
2°	Bulgaria	Bulgaria	France	France	France	France	France	France	France	France	Bulgaria	Bulgaria	Bulgaria	Bulgaria	France
3°	Estonia	Estonia	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Bulgaria	Estonia	Estonia	Estonia	Estonia	Bulgaria
4°	Luxembourg	France	Estonia	Estonia	Estonia	Estonia	Estonia	Estonia	Estonia	Estonia	Luxembourg	Luxembourg	Luxembourg	France	Estonia
5°	France	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	Luxembourg	France	France	France	Luxembourg	Luxembourg
6°	Italy	Italy	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal	Italy	Italy	Italy	Italy	Italy
7°	Spain	Portugal	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Spain	Portugal
8°	Portugal	Spain	Greece	Greece	Greece	Greece	Greece	Greece	Greece	Greece	Portugal	Portugal	Portugal	Portugal	Spain
9°	Greece	Greece	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Cyprus	Greece	Greece	Greece	Greece	Greece
10°	Cyprus	Cyprus									Cyprus	Cyprus	Cyprus	Cyprus	Cyprus

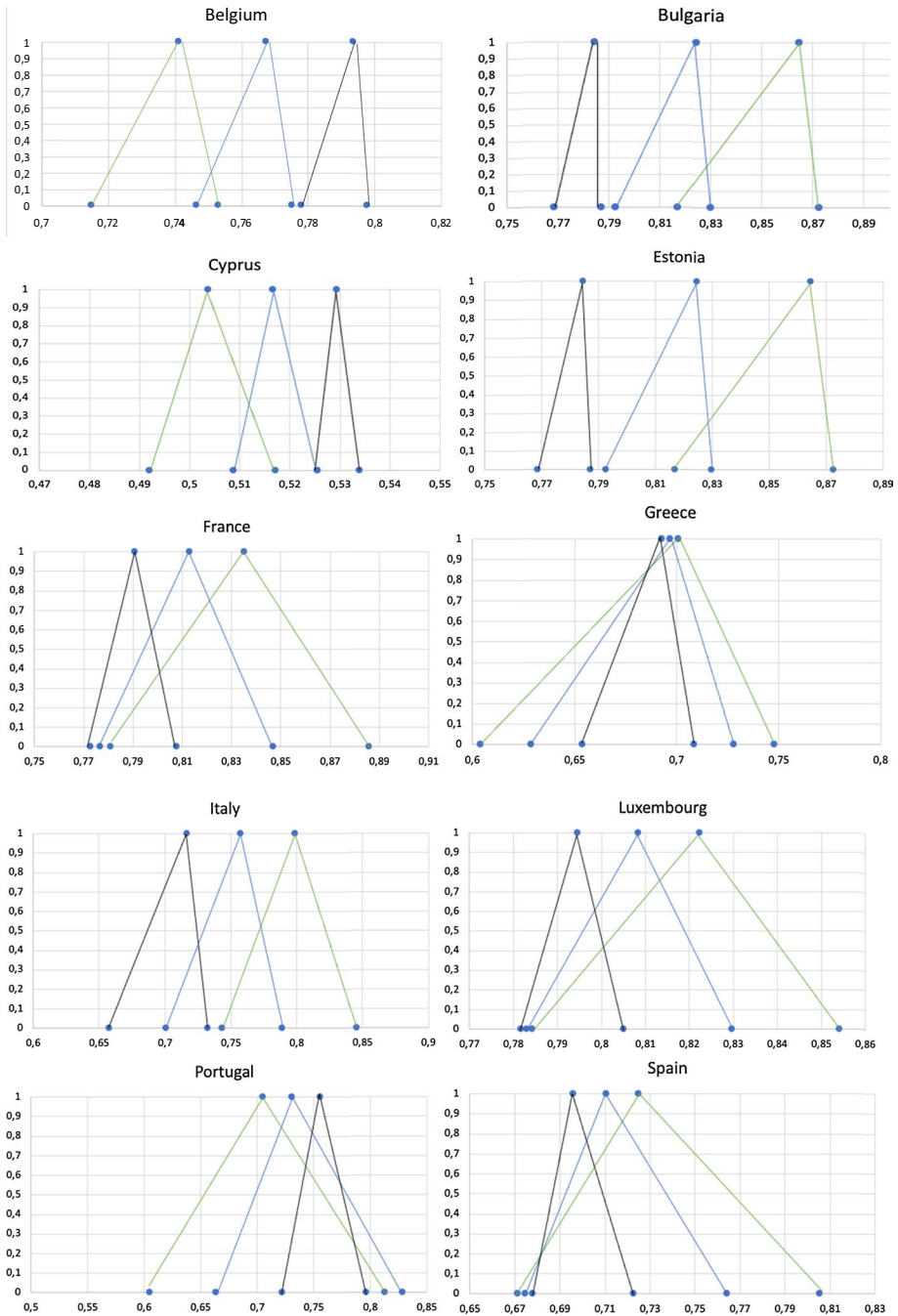


Fig. 1 Triangular fuzzy charts that represent the results of the FWSI when Capacity and Resilience weights are 0.5 (green), Capacity and Resilience weights are 0.25 and 0.75 respectively (black) and Capacity and Resilience weights are 0.75 and 0.25 respectively (blue)

exploitation index. Although marked negative trends were detected in the availability of renewable water resources in all countries, except in France, which shows very irregular interannual behavior in all indicators associated with capacity. On the other hand, indicators associated with the anthropogenic impact on water, such as the exploitation index or nutrient concentration, showed an upward or irregular trend in all countries, except in Cyprus and Luxembourg. The worst water exploitation data was for Cyprus, although with a decreasing trend. Luxembourg and Belgium are interesting cases. Both countries show some of the worst results in the indicators associated with anthropogenic impact (1.2., 1.3., 1.4.), however, they are the countries that have improved the most over the series, i.e. they have reduced their impact on water to a greater extent.

On the other hand, the asymmetry of the triangle indicates the propensity of the country to obtain the best results, the worst results or stable results. For example, Belgium's graph shows a slight positive asymmetry that can be explained by the good performance over time of the indicators associated with the anthropogenic impact on water resources. The results on capacity are consistent with those of the Water Risk Atlas (WRI, 2021), however, when resilience indicators are considered, the results change. By assigning more weight to resilience indicators (black triangles in Fig. 1) the scores and rankings change. Belgium, Cyprus and Portugal improve their results compared to the scores that prioritize capacity. In the case of Belgium and Portugal, this translates into better ranking positions. Cyprus, on the other hand, performed so poorly that this advantage was not enough to move it out of the worst overall position. Belgium obtained the best positions in all resilience indicators, except for the one associated with climate change, although the trend of the series is slightly decreasing. Luxembourg again shows poor results in the indicators associated with anthropogenic pressure on resilience (2.1. and 2.2.) but again shows the strongest reduction in these indicators over the series, as is the case for many of its capacity indicators.

Incorporating the resilience of countries to face difficulties associated with the sustainable management of water resources, whether environmental (climate change control, soil erosion control or protection of aquatic ecosystems), social or economic (good governance, water productivity), implies incorporating a forward-looking approach in the design of international policies. While capacity indicators measure the state (in quantity, quality and access) of water resources, resilience indicators measure the capacity of countries to manage these resources in a sustainable manner. The conflicts inherent in the use of common resources such as water, make their sustainable management practically impossible without a culture of good governance that establishes a balance in the power relationships between the different social actors to encourage the choice of cooperative strategies (Vollan & Ostrom, 2010).

Bulgaria and Estonia recorded the largest changes when resilience was given greater importance. Both countries recorded the worst productivity scores, with the smallest growth rates since 2010. Estonia also had the worst scores for climate change and no significant improvement over the series, and Bulgaria had the worst scores for good governance. The cases of Estonia and, above all, Bulgaria are of particular interest for two reasons. Both are countries with good quality water resources that are not overexploited due to low anthropogenic pressure. Considering only the quantity and quality of water resources they have obtained the best positions in the ranking. However, the resilience results show limited institutional development. Given a potential scenario of economic development in these countries, it is to be expected that if the deficiencies associated with good governance and water productivity issues are not addressed, the relative advantages in terms of capacity will disappear, making it very difficult to control the impact of demographic and

economic expansion on their water resources. In fact, at the end of 2020, the Council of Ministers adopted the *Bulgarian National Development Program 2030* which focuses on three main strategic objectives: accelerated economic development, demographic growth and reduction of inequalities (UNESCO, 2022). Both accelerated economic growth and population growth could seriously compromise Bulgaria's water capacity if institutional constraints are not resolved.

Although Bulgaria's approach to advancing towards the SDGs with environmental actions has water management as one of its priorities (SDG 6), it would be advisable to focus efforts on policies aimed at improving the detected institutional limitations. In this sense, the limitations associated with water productivity in these countries also compromise the sustainable management of water resources and may affect capacity indicators in the face of a scenario of economic development and population growth that requires large volumes of water in an inefficient manner. Once again, we are faced with a cross-cutting problem, which could only be solved by implementing policies for the development of the knowledge economy, for example.

The sustainability of water resources cannot be addressed independently by each country. The process of globalization generates externalities in the water footprint (the total volume of water used to produce all the commodities consumed by the citizens of each country) of the countries and regions of the world derived from imports and exports of water-consuming products. The limits of supply chains exceed the scope, not only of companies, but even of countries (Skare & Ribeiro Soriano, 2021). This means that water needs to produce commodities must be analyzed from a broader perspective. As a result, countries import and export virtual water. For example, global trade in agricultural commodities alone generates international virtual water flows amounting to 1250 billion cubic meters per year (Gruener, 2010).

The heavy dependence of many countries, such as those in Europe, on exports from countries such as Brazil of water-intensive commodities such as cotton, sugar and soybeans, perfectly illustrates the need to address the problem of water sustainability from an international perspective. The cross-cutting, transboundary nature of water resources requires the design of globally coordinated water policies. The indicator proposed in this paper can contribute to the design of these policies by providing fuzzy information that facilitates the early identification of problems and the orientation of international strategic plans. The global approach of worldwide societies and economies requires more and more time that the nations, regions, industries and enterprises pursue a *sustainability identity* (Bouncken et al., 2022) from a particular approach in order to guarantee the sustainability of the world.

5 Conclusions

This paper proposes an indicator based on a fuzzy-DEA model to measure the sustainability of countries in terms of water based on time series. The proposed indicator was able to provide fuzzy information using fuzzy triangular numbers from three scenarios, considering the capacity of countries in terms of quality, quantity and accessibility of renewable water resources and their ecological, social and economic resilience. The indicator was useful in providing early warning signals for countries whose water sustainability may be compromised in the future by factors associated with their institutional constraints or water productivity. The diffuse nature of the information provided by the indicator makes it

possible to define scenarios and detect pronounced trends and irregular behavior over time with respect to countries' water capacity and resilience.

The application of the indicator to ten water risk hotspots in the EU made it possible to identify some countries that require urgent attention, either because of their alarming situation in terms of capacity and resilience, or because of their weak resilience that compromises the sustainability of their water resources. Cyprus was by far the worst performer, both in terms of capacity and resilience. Some countries such as Belgium, which have maintained a strong impact on their water resources, have a resilience that allows them to improve their scores throughout the series analyzed. Other countries such as Bulgaria, Italy and Estonia worsened their position in the ranking when resilience was included in the indicator. Attention should be paid to countries such as Bulgaria, with strong institutional constraints and medium-term economic development and population growth projections. Although it currently has the best position in terms of water capacity among the countries analyzed, its institutional weaknesses could compromise the sustainability of its water resources. It should be borne in mind that even the best positions in the ranking presented in this paper are not good positions, since the countries analyzed are the countries with the highest water risk in the EU.

The results in terms of resilience were robust in the three scenarios analyzed, as opposed to the results in terms of capacity, which presented greater variability. Incorporating the resilience of countries provides a long-term perspective to water sustainability indicators. This can be very useful for planning international policies with a broad horizon and a forward-looking approach. The cross-cutting and global nature of water resources means that sustainable water management must be addressed with an international approach, implementing coordinated policies at the global level. In this sense, the proposed indicator can contribute to the design of international water policies, providing information in scenarios and in terms of benchmarking, and simultaneously considering the water capacity of countries and their resilience.

The main limitations of this work are associated with data availability. Although the proposed method overcomes some limitations associated with the lack of time series data by providing fuzzy information, it is essential to have updated databases to be able to identify problems sufficiently in advance. As a recommendation, the authors highlight that, although the EU has a homogeneous and relatively complete database, it is necessary to continue making efforts to update these databases. It is also necessary to promote and support the creation of databases on water resources in countries with low GDP, which are strong exporters of virtual water and are part of the global supply chain of countries with greater resources, such as the EU.

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Declarations

Conflict of interest The authors declare that there are no conflict of interest, financial or otherwise, directly or indirectly related to this work.

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