Sustainable Technology and Entrepreneurship 1 (2022) 100022

ELSEVIER

Sustainable Technology and Entrepreneurship

https://www.journals.elsevier.com/sustainable-technology-and-entrepreneurship

Full Length Article

Constructing fuzzy composite indicators to support water policy entrepreneurship

Amelia Pérez Zabaleta[a], Pascual Fernández[b], Juan F. Prados-Castillo[c], Mónica de Castro-Pardo[d,*]

[a] Department of Applied Economics, UNESCO UNED-URJC Chair in Water and Peace, UNED, Calle Bravo Murillo 38, Madrid 28015, Spain
[b] Department of Applied Economics I and history and economic institutions, Faculty of Law and Social Sciences, Universidad Rey Juan Carlos, Campus of Vicálvaro, Tulipan, 28933 Móstoles, Madrid, Spain
[c] Department of Applied Economics, Faculty of Economics and Business Sciences, University of Granada, Campus de la Cartuja, Granada 18011, Spain
[d] Department of Financial and Actuarial Economics and Statistics-Statistics and, Operational Research, Complutense University of Madrid, Campus of Somosaguas, Pozuelo de Alarcon, Madrid 28223, Spain

ARTICLE INFO

Article History:
Received 20 May 2022
Accepted 20 June 2022

Keywords:
Water policy entrepreneurship
Fuzzy
Indicators
DEA
Water conflicts
Pressure-state-response framework

ABSTRACT

Composite indicators play a very useful role in supporting international policy entrepreneurship, helping to inform decision-making processes and to address conflicts between countries. In this paper we present a Fuzzy Data Envelopment Analysis (Fuzzy-DEA) model to construct composite indicators based on time series under the Pressure-State-Response (PSR) approach in order to evaluate water security in 10 European water security hotspots. First, we identified nine indicators within the PSR framework. Second, we aggregated the indicators in each PSR set using a Fuzzy-DEA model. Finally, we compared the PSR results under pessimistic, optimistic and neutral scenarios. Results show that, overall, Bulgaria achieved the best pressure, state and response performance. In terms of responses, Spain registered the best performance after Bulgaria, despite the fact that it suffers from the highest pressures of all the analyzed countries. Estonia achieved the best state performance in all three scenarios, but worse results in responses than Bulgaria and Spain. Cyprus and Belgium registered the highest variability for pressures, Spain for state and Portugal for responses.
The model was able to pinpoint the problems that political strategies and urgent actions should seek to tackle, while providing information regarding the variability of the indicators over time.

Introduction

The concept of policy entrepreneurship lends itself to the analysis of how actors at the international level draw attention to problems, present viable proposals and link results to symbolic values. The international space is a challenging arena for policy advocacy as it lacks the oversight and well-established systems of policy development commonly found at the national or subnational level.

Policy entrepreneurs operating in the international space face different obstacles and opportunities to their national counterparts, particularly in the areas of policy initiation, mediation and engagement (Mintrom & Luetjens, 2017). In this context, it is necessary to develop control mechanisms to assess the appropriate implementation of public policies, monitor them over time and develop rigorous decision-making processes that can accommodate the preferences of different stakeholders.

This situation is particularly complex when it comes to water policy, as difficulties arise due to the transboundary nature of water and conflicts between different stakeholders at international, national and regional levels. Furthermore, the current global water crisis plays an undeniably important role in economies, societies and, ultimately, human survival (Buchs et al., 2021) de Castro-Pardo et al. (2021). As such, there is a need for information to be generated on the present state of resource sustainability. Water security “is a dynamic concept that evolves with stakeholder interests and may involve freshwater supply, water scarcity, water management, flood risk, and national security” (Dou et al., 2021; Howlett & Cuenca, 2017).

In Europe, recent EU directives reflect the concern about the need to develop policies that improve water security. These include the European Union Water Framework Directive (2000/60/EC; 22 December 2000, OJ L 327), which provides a guide for new European water policy based on a markedly integrative approach.

* Corresponding author.
E-mail address: monica.decastro@ucm.es (M. de Castro-Pardo).

https://doi.org/10.1016/j.stae.2022.100022

Although Europe's annual renewable freshwater resources are relatively abundant (reaching 4560 m3 per person for the period 1990−2017), considerable differences are observed at the national level. These differences are caused by variations in climate conditions and population distribution (Eurostat, 2022), and can be a particular source of conflict in decision-making processes.

Against this backdrop of complicated decision-making, it is particularly useful to have methodological tools that facilitate decision-making processes, help channel negotiation processes between the countries involved, optimize the allocation of available resources and provide a rigorous guide for the planning of international water security strategies.

Composite indicators are especially useful for describing complex realities involving numerous variables (D'Inverno et al., 2021; Guaita et al., 2020), and particularly for the planning and implementation of public policies on hard-to-measure phenomena such as water security. These indicators provide a global overview based on the partial information provided by a group of partial indicators. The interest in composite indicators lies in their ability to synthesize information and the valuable tool they provide for decision-making (De Castro-Pardo et al., 2022). This approach is very useful for policymakers, researchers, analysts, and so on, providing a single data point on which they can base their analysis of a phenomenon (Kenny et al., 2019).

However, the construction of composite indicators is not without its difficulties. In particular, when designing sustainability indicators, care should be taken in the normalization, weighting and aggregation processes (Ruiz & Cabello, 2021). The weighting and the definition of weights is critical in the design of composite indicators as it can influence the end result (Ruiz & Cabello, 2021). Furthermore, when using time series, the way in which the data are incorporated into the composite indicator can also be very important. In terms of weights, equal weighting schemes are typically used. Regarding the treatment of time series data, the arithmetic mean of the data series or the most recent value are commonly used. The equal weighting scheme is not a neutral system, although it tends to be used as if it were. Replacing the values included in a time series with the mean or the most recent value results in a loss of information about the variability of the data over time.

In this article, we present a fuzzy model based on Benefit of the Doubt-Data Envelopment Analysis (BoD-DEA) to construct three composite indicators associated with Pressures, State and Responses, applied to measure water security. The fuzzy approach makes it possible to capture the variability in the time series through asymmetric triangular fuzzy numbers. The BoD-DEA model allows us to identify the best weights for the indicators of each country in terms of optimization benchmarking.

Section 2 describes the methodology used to construct the indicators, while Section 3 presents and analyzes the results of an application of the methodology to measure water security in 10 European countries identified as water security hotspots. Finally, some conclusions are drawn in Section 4.

Methodology

The pressure-state-response approach

A Pressure-State-Response (PSR) approach has been used for the identification and analysis of the indicators.

The OECD relies on the PSR framework as the basis for a classification of indicators (of environmental pressures, environmental conditions and social responses) using a series of elements reflecting the primary environmental concerns in OECD countries (OECD, 2013).

The PSR framework involves identifying the factors that exert pressure on the state of environmental resources, especially human activities; the elements that enable a measurement of the state of resources; and the social, economic and environmental response by agents, instrumentalized through institutions (Yee et al., 2015).

This framework has been widely used at the international level, although it can also be applied at the subnational level, for regional, local or sectoral analysis. It has been successfully applied in many areas such as fisheries, forest management and water security (Zhao et al., 2021). Particularly, the PSR approach has been applied in several worldwide studies to assess water security, such as Dou et al. (2021) in the Yangtze River (China), Marangoz and Daloglu (2022) in Turkey's Aegean Region or Scott and Luzt-Ley (2016) in Arizona (USA) and Sonora (Mexico).

Fuzzy DEA models

Data envelopment analysis (DEA) is based on mathematical programming and is aimed at measuring the relative efficiency of a homogeneous set of decision making units (DMUs) in relation to multiple inputs and multiple outputs (Charnes et al., 1978). In recent decades, DEA has been applied as a powerful optimization tool to model operational processes in terms of benchmarking, performance evaluation and decision-making (Koronakos et al., 2021; Guaita Martínez et al., 2020·; Omrani et al., 2020·; Verbunt and Rogge, 2018). DEA models have been applied to assess water security through different approaches (De Castro-Pardo et al., 2022; Yao et al., 2020).

In particular, the Benefit of the Doubt (BoD) approach based on DEA models has been used to construct composite indicators in settings of imprecise information. The BoD model makes it possible to position the performance of a DMU relative to all the other DMUs and assign the highest weights to the indicators in which it achieves its best score, lower weights to the second-best indicator, and so on, such that the model selects the most favorable set of weights for each unit of analysis (Lafuente et al., 2020).

Fuzzy logic can be a very useful approach for dealing with imprecision and vagueness in DEA-type models, yielding comprehensive results (Mu et al.; 2018). Fuzzy numbers were formulated by Zadeh (1965) and are based on the simple idea of introducing a degree of membership of an element. Fuzzy-DEA models take the form of a fuzzy linear programming model with fuzzy coefficients in both the objective function and in the constraints, such that some fuzzy operations including 'maximizing a fuzzy variable' and 'fuzzy inequality' may be required (Hatami-Marbini et al., 2013). This paper puts forward a basic model that uses non-symmetrical triangular fuzzy functions.

Following the approach employed by Shen et al. (2011), we propose three crisp linear programming models using triangular fuzzy indicators $\tilde{I}_{rj}$, which can be denoted with the ir center and spreads as $I_{rj} = (i_{rj} \propto^{l}_{rj} \propto^{r}_{rj}) r = 1, s, j = 1, n$

The model described in Eqs. (1)–(6) allows the construction of a fuzzy index to the pressures associated to water security (FPI) including the indicators described in Section 2.1.

$$FPI_0 = \max \lambda_1^P \sum_{r=1}^{s} w_r^P \left(i_{r0}^P - (1-t) \propto_{r0}^{lP} \right) + \lambda_2^P \sum_{r=1}^{s} w_r^P \left(i_{r0}^P + (1-t) \propto_{r0}^{rP} \right) \quad (1)$$

s.t.

$$\sum_{r=1}^{s} w_r^P \left(i_{rj}^P - (1-t) \propto_{rj}^{lP} \right) \le 1 j = 1, n \quad (2)$$

$$\sum_{r=1}^{s} w_r^P \left(i_{rj}^P + (1-t) \propto_{rj}^{rP} \right) \le 1 j = 1, n \quad (3)$$

$$\sum_{r=1}^{s} w_r^P = 1 \quad (4)$$

$$w_r^P \geq \delta_r^P \quad (5)$$

$$\lambda_1^P + \lambda_2^P = 1 \quad (6)$$

where EPI_0 is the fuzzy pressure indicator for country 0, W_r^p are the weights associated with each capacity indicator r, i_{rj}^p is the center of the fuzzy number that represents the capacity indicator r for country j and is the mean value of all the indicators included in a time series, $\propto_{rj}^{lP}$ and $\propto_{rj}^{rP}$ are the left and right spreads of indicator r for country j and represent, respectively, the distance between the mean value of all indicators that are part of a time series and the minimum indicator value and the distance between the mean value and the maximum value of the series. t is the possibility level that models the range of the fuzzy number and takes the values 0 and 1, such that when t is zero, we consider only the central value of the fuzzy number and not the spread. The parameters λ_1^P and λ_2^P take values between 0 and 1 and yield results under three scenarios: optimistic, when $\lambda_1^P = 0$, pessimistic, when $\lambda_1^P = 1$ and neutral, when $\lambda_1^P = \lambda_2^P$.

The value of the parameter δ_r^P indicates the minimum acceptable value for the weights of each indicator, representing the minimum relative importance that should be given to each indicator.

The equivalent state (FSI) and response (FRI) composite indicators have been constructed using similar models to aggregate the indicators included in the state and response sets.

The original indicators are normalized using a min-max scaling method. The normalized scores are then fuzzified, taking the mean of all the values in the series as the mean value of the triangle and calculating the left and right spreads by subtracting the minimum indicator score from the mean value and subtracting the mean value from the maximum value of each series, respectively.

Results and discussion

Indicators and data

The proposed model has been applied to the 10 European Union countries identified has having the greatest water risk by the Aqueduct Project of the World Resources Institute (WRI, 2022): Belgium, Bulgaria, Cyprus, Estonia, France, Greece, Italy, Luxembourg, Portugal and Spain. The Water Risk Atlas mapping tool analyzes current and future water risks across locations and includes indicators of physical risk quantity, physical risk quality, and issues regarding drinking water and sanitation for the population.

To assess water security, a total of nine indicators have been identified: three for pressures, three for state and three for responses. They are described in Fig. 1. The time series referring to these indicators have been collected from four international databases: Eurostat, Aquastat-Food and Agriculture Organization (FAO), European Environment Agency (EEA) and United Nations (UN). Data were collected for the period 2000−2019.

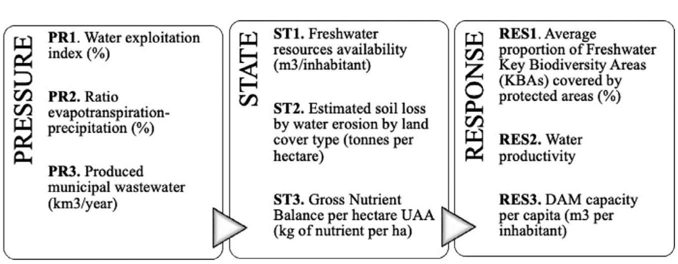

Fig. 1. Pressure-state-response indicators to assess water security.

The paragraphs below explain each indicator identified to measure pressures on water resources, the state of water resources and (appropriate) responses in terms of water policies. The indicators were classified as "more is better" (+) or "less is better" (-). The unit of measurement for each indicator is also noted.

PR Indicators. Pressures on water resources:

PR1: Water exploitation index (-): This index shows the mean annual total demand for freshwater divided by the average long-term freshwater resources. It gives an indication of how the total water demand puts pressure on water resources (EEA, 2022).

PR2: Evapotranspiration-precipitation ratio (-): Given as a percentage, it represents the proportion of water that evaporates (in millions of m3) per million m3 of precipitation (Eurostat, 2022).

PR3: Produced municipal wastewater (-): Annual volume of domestic, commercial and industrial effluents, and storm water runoff, generated within urban areas (FAO, 2022). It is measured in km3/year.

ST Indicators. The state of water resources:

ST1: Freshwater resources availability (+): This indicator represents the volume of total available water resources per inhabitant. It is measured in m3/inhabitant (Eurostat, 2022).

ST2: Estimated soil loss by water erosion (-): This indicator represents the loss of soil due to erosion by water measured in tons per hectare. Soil erosion caused by water is one of the main threats to soils in the European Union, with a negative impact on ecosystem services, crop production, drinking water and carbon sinks (Eurostat, 2022; Panagos et al., 2015).

ST3: Gross Nutrient Balance per hectare Utilized Agriculture Area (UAA) (-): It is calculated as the "total gross nitrogen surplus divided by the reference area" and provides an indication of the potential surplus of nitrogen (N) on agricultural land. It is measured in kg N per ha per year (Eurostat, 2022). It is a measure of water pollution due to excess nutrients.

RES Indicators. Response-adequacy of water management:

RES1: Average proportion of Freshwater Key Biodiversity Areas covered by protected areas (+): This indicator represents the percentage of protected Freshwater Key Biodiversity Areas Eurostat (2022).

RES2: Water productivity (+): It indicates how much economic output is produced per cubic meter of fresh water abstracted and measures the efficiency of water use. Total freshwater abstraction includes water abstracted from any freshwater source, whether permanently or temporarily. The indicator includes surface and groundwater sources but excludes water used for hydroelectric power generation (Eurostat, 2022).

RES3: Dam capacity per capita (+): This indicator measures the total dam storage capacity per capita and represents a country's capacity for water storage. It is measured in m3 per inhabitant (FAO, 2022).

Results

Tables 1−3 show the normalized minimum (Min), maximum (Max) and mean values (Mean), together with the lef ($**$) and right ($**$) spreads, for pressure, state and response indicators, respectively. From the values presented in these tables, the fuzzy values of the normalized indicators can be easily deduced. It should be recalled that each triangular fuzzy number $\tilde{I}_{rj}$ can be denoted with its center and spreads as $\tilde{I}_{rj} = (i_{rj} \propto^{l}_{rj} \propto^{r}_{rj}) r = 1, s, j = 1, n$

Spreads provide valuable information that can be used to easily identify the dispersion of each time series; that is, the variability of an indicator over time. They also provide information about the asymmetry of the triangle, which represents the propensity of the series to generate values closer to the minimum value or to the maximum value.

After aggregating the indicators in each block (pressures, state, responses) using the models described in Section 2.2., the values of

Table 1
Normalized scores of the analyzed pressure indicators; minimum, maximum, mean and left and right spreads.

PRESSURE	PR1					PR2					PR3				
Countries	Min	Max	Mean	$\propto_l$	$\propto_r$	Min	Max	Mean	$\propto_l$	$\propto_r$	Min	Max	Mean	$\propto_l$	$\propto_r$
Belgium	0,6874	0,9603	0,9101	0,2226	0,0502	0,5443	1,0000	0,7770	0,2327	0,2230	0,7636	0,8360	0,8168	0,0532	0,0192
Bulgaria	1,0000	1,0000	1,0000	0,0000	0,0000	0,1936	0,7979	0,3718	0,1782	0,4260	0,8765	0,9164	0,8874	0,0108	0,0290
Cyprus	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1317	0,0132	0,0132	0,1186	0,9973	0,9989	0,9982	0,0009	0,0007
Estonia	0,5417	0,9258	0,8059	0,2642	0,1200	0,5860	1,0000	0,7918	0,2058	0,2082	0,9282	0,9868	0,9569	0,0286	0,0299
France	0,8242	0,9751	0,9419	0,1177	0,0333	0,5767	1,0000	0,7488	0,1721	0,2512	0,0502	0,2326	0,1836	0,1334	0,0489
Greece	0,0000	0,6782	0,5277	0,5277	0,1505	1,0000	1,0000	1,0000	0,0000	0,0000	0,8599	0,8945	0,8854	0,0255	0,0091
Italy	0,7075	0,9003	0,8366	0,0604	0,0708	0,8526	1,0000	0,9596	0,1070	0,0404	0,0000	0,2469	0,1819	0,1819	0,0650
Luxembourg	0,8601	0,9924	0,9604	0,1003	0,0319	0,8175	0,8175	0,8175	0,0000	0,0000	1,0000	1,0000	1,0000	0,0000	0,0000
Portugal	0,6484	0,9149	0,8307	0,1823	0,0843	0,0000	0,8749	0,4051	0,4051	0,4698	0,8909	0,9011	0,8944	0,0035	0,0067
Spain	0,2566	0,8289	0,6939	0,4373	0,1349	0,4445	0,7365	0,6011	0,1566	0,1354	0,0000	0,0046	0,0012	0,0012	0,0035

Table 2
Normalized scores of the analyzed state indicators; minimum, maximum, mean and left and right spreads.

STATE	ST1					ST2					ST3				
Countries	Min	Max	Mean	$\propto_l$	$\propto_r$	Min	Max	Mean	$\propto_l$	$\propto_r$	Min	Max	Mean	$\propto_l$	$\propto_r$
Belgium	0,0989	0,1661	0,1403	0,0414	0,0258	0,8850	0,8952	0,8911	0,0062	0,0041	0,2495	0,3755	0,3052	0,0556	0,0703
Bulgaria	0,4933	1,0000	0,9148	0,4216	0,0852	0,7080	0,7476	0,7296	0,0217	0,0179	0,9956	1,0000	0,9993	0,0036	0,0007
Cyprus	0,0000	0,0000	0,0000	0,0000	0,0000	0,6903	0,7143	0,7044	0,0142	0,0099	0,0000	0,0000	0,0000	0,0000	0,0000
Estonia	1,0000	1,0000	1,0000	0,0000	0,0000	1,0000	1,0000	1,0000	0,0000	0,0000	0,8903	0,9720	0,9229	0,0326	0,0492
France	0,0753	0,6145	0,2301	0,1548	0,3844	0,8053	0,8286	0,8165	0,0112	0,0121	0,5586	1,0000	0,8852	0,3266	0,1148
Greece	0,5509	0,5509	0,5509	0,0000	0,0000	0,5752	0,5825	0,5796	0,0043	0,0030	0,6789	0,8341	0,7798	0,1009	0,0543
Italy	0,5672	0,5672	0,5672	0,0000	0,0000	0,0000	0,0000	0,0000	0,0604	0,0708	0,0000	0,7714	0,5422	0,0604	0,0708
Luxembourg	0,1135	0,7228	0,4182	0,3046	0,3046	0,7168	0,7238	0,7197	0,0029	0,0041	0,3147	0,3935	0,3596	0,0449	0,0339
Portugal	0,1195	1,0000	0,3860	0,2665	0,6140	0,7168	0,7524	0,7325	0,0156	0,0199	0,6992	0,9018	0,8420	0,1428	0,0598
Spain	0,0418	0,4121	0,1400	0,0982	0,2721	0,5752	0,6095	0,5956	0,0203	0,0140	0,6493	1,0000	0,8951	0,2458	0,1049

Table 3
Normalized scores of the analyzed response indicators; minimum, maximum, mean and left and right spreads.

RESPONSES	RES1					RES2					RES3				
Countries	Min	Max	Mean	$\propto_l$	$\propto_r$	Min	Max	Mean	$\propto_l$	$\propto_r$	Min	Max	Mean	$\propto_l$	$\propto_r$
Belgium	0,9400	0,9565	0,9455	0,0055	0,0109	0,0652	0,0883	0,0749	0,0097	0,0135	0,0000	0,0000	0,0000	0,0000	0,0000
Bulgaria	0,9646	0,9681	0,9668	0,0022	0,0013	0,0000	0,0000	0,0000	0,0000	0,0000	0,5873	0,7995	0,7049	0,1177	0,0946
Cyprus	0,0000	0,0000	0,0000	0,0000	0,0000	0,0630	0,1077	0,0793	0,0163	0,0284	0,2190	0,2623	0,2328	0,0137	0,0296
Estonia	1,0000	1,0000	1,0000	0,0000	0,0000	0,0020	0,0036	0,0028	0,0007	0,0009	0,0846	0,1105	0,1005	0,0159	0,0100
France	0,5677	0,6209	0,5915	0,0238	0,0294	0,0664	0,0764	0,0704	0,0040	0,0060	0,1213	0,1277	0,1247	0,0034	0,0030
Greece	0,8900	0,8932	0,8920	0,0020	0,0012	0,0096	0,0158	0,0119	0,0023	0,0039	0,8245	1,0158	0,9268	0,1024	0,0890
Italy	0,8447	0,8478	0,8462	0,0604	0,0708	0,0345	0,0345	0,0345	0,0604	0,0708	0,1153	0,1370	0,1286	0,0134	0,0084
Luxembourg	0,0098	0,0098	0,0098	0,0000	0,0000	1,0000	1,0000	1,0000	0,0000	0,0000	0,0789	0,1053	0,0939	0,0150	0,0114
Portugal	0,4816	0,4833	0,4824	0,0008	0,0009	0,0281	0,0281	0,0281	0,0000	0,0000	0,5484	0,9833	0,8392	0,2909	0,1441
Spain	0,1991	0,2077	0,2056	0,0064	0,0022	0,0248	0,0286	0,0262	0,0014	0,0025	1,0000	1,0000	1,0000	0,0000	0,0000

the composite indicators for pressures, state and responses were generated in three scenarios: pessimistic (t = 0, λ_1^j=1), optimistic (t = 0, λ_1^j=0) and neutral (t = 1). Note that the results generated for λ_1^j= 0 or λ_1^j=1 when t = 1 are equal.

These results are depicted graphically in Figs. 2–4, respectively.

Table 4 shows the ranking of the countries analyzed in each of the scenarios.

In all three scenarios, Spain is subject to the greatest pressures. Despite this, it registers the second best performance for the response indicator in the pessimistic scenario and the third best in the neutral scenario. One of the highest pressures on water security in Mediterranean countries is related to indicators of water exploitation derived from population growth and evapotranspiration. Marangoz and Daloglu (2022) found similar results regarding these variables following a PSR approach as well in Turkey's Aegean Region. Usually geographical and climatic factors affect the water security of some regions. For example, Dou et al. (2021) identified some of these types of

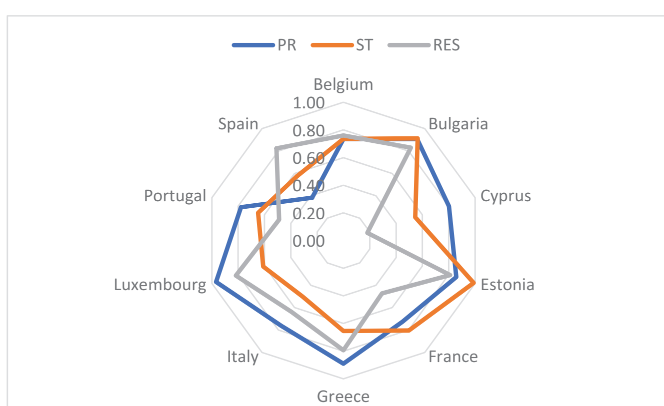

Fig. 2. PSR results in a pessimistic scenario.

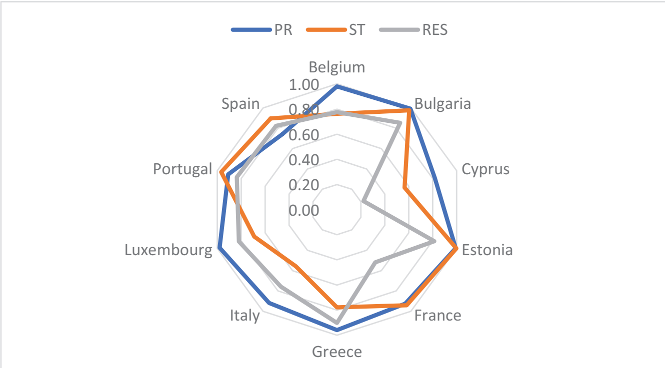

Fig. 3. PSR results in an optimistic scenario.

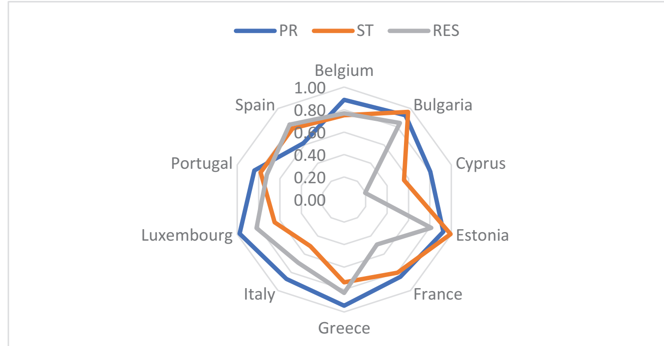

Fig. 4. PSR results in a neutral scenario.

Table 4
Ranking by country, scenario and PSR indicators.

Scenarios	Pessimistic			Optimistic			Indifferent		
Countries	Rank PR	Rank ST	Rank RES	Rank PR	Rank ST	Rank RES	Rank PR	Rank ST	Rank RES
Belgium	8	4	6	4	7	7	5	6	6
Bulgaria	2	2	1	1,2	2	2	3	2	1
Cyprus	5	9	10	9	9	10	9	9	10
Estonia	4	1	4	1,2	1	6	4	1	5
France	9	3	9	6	4	9	7	3	9
Greece	3	5	5	5	6	1	2	7	2
Italy	7	10	7	7	10	8	6	10	8
Luxembourg	1	7	3	3	8	5	1	8	4
Portugal	6	6	8	8	3	3	8	5	7
Spain	10	8	2	10	5	4	10	4	3

relationships regarding high-low comprehensive water security in 15 key cities in the Yangtze River Delta (China).

The opposite can be seen for Cyprus, which registers some of the worst scores in all three indicators in all scenarios (9th and 10th positions), although its performance for the pressures indicator in the optimistic scenario is not quite as bad (5th position).

Overall, Bulgaria performs the best in all scenarios and for all three indicators.

Estonia registers the best performance for the state indicator under all three scenarios, although it achieves worse results for its response indicator than countries such as Bulgaria or Spain.

Cyprus shows the greatest variability for pressures, Spain for state and Portugal for responses.

The variability of Cyprus in the pressure indicator is primarily due to substantial interannual variability in the evapotranspiration-precipitation ratio and an increase in the generation of wastewater.

The variability in Spain's state indicator can mostly be attributed to the interannual variability in the availability of water resources and the marked increase in nutrient pollution in the last year analyzed (2016–2017). Although the variability associated with the availability of water resources is very hard to control due to Spain's severe water seasonality, it would be highly advisable to review the most recent data on the concentration of nutrients per ha to determine whether this change is an isolated event or if it has been corrected, and to evaluate the extent of the problem.

The variability shown by Portugal is based on the sharp and continuous increase in its water storage capacity (RES3-DAM capacity pc) throughout the entire series analyzed, registering a rise of about 50% from the beginning of the series until 2018.

It should be borne in mind that the countries analyzed are those that face the greatest water security risks in the European Union. This means that even the best results for state and pressure indicators are very bad. Particularly noteworthy in this context are the countries that perform best in their response indicator, such as Bulgaria, Spain or Greece. These countries appear to have been able to appropriately target their water policies to improve their water security.

By applying the PSR approach, it has been possible to generate aggregate information associated with different levels of analysis. Compared to the use of global indicators, this approach provides more specific information useful for identifying water security problems, informing decision-making and implementing conflict resolution processes. Furthermore, the fuzzy approach has made it possible to include information on the temporal variability of indicators in the construction of the PSR indictors.

This approach could be very useful for supporting the development and implementation of European water policies since it provides a wealth of specific information on the problem of water security, its current status and countries' level of commitment to addressing it.

It should be borne in mind that, as always when using a benchmarking approach, these results would change if an element of analysis or a country were added or removed.

Conclusions

The Fuzzy Pressure-State-Response approach has proven beneficial in providing a wealth of information to support international policy entrepreneurship, particularly when it comes to decision-making processes. It can generate aggregate but independent information on the problem of water security, the current status and countries' level of commitment to addressing it. This methodology makes it possible to pinpoint problems, closely monitor them, identify specific solutions and accurately guide the negotiation processes related to international water policies, which can be a particular source of conflict.

By applying the fuzzy time series approach, temporal variability can be incorporated into the construction of the indicators, helping to detect anomalous behavior and the sudden emergence of trends at each level of analysis.

In the case study presented here, the application of the proposed model focuses on the countries that suffer the greatest water pressure, including Spain, Cyprus and France. The findings identify the countries that have shown the strongest response to water security problems, such as Bulgaria and Spain, and those that have substantially improved in some of these responses, such as Portugal. Bulgaria and Estonia achieved the best results in the state indicator and also the most stable over time.

The main limitations of the study are linked to the quality of the information. Although there are many international databases on water resources, they need to be updated on a regular basis.

Future research could be aimed at applying PSR models to regional and national case studies where there are serious conflicts over the use of water.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Buchs, A., Calvo-Mendieta, I., Petit, O., & Roman, P. (2021). Challenging the ecological economics of water: Social and political perspectives. *Ecological Economics*, *190*, 107176. doi:10.1016/j.ecolecon.2021.107176.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444.

De Castro-Pardo, M., Fernández Martínez, P., Pérez-Zabaleta, A., & Azevedo, J. C. (2021). Dealing with water conflicts: A comprehensive review of MCDM approaches to manage freshwater ecosystem services. *Land*, *10*(5), 469.

De Castro-Pardo, M., Fernández Martínez, P., & Pérez Zabaleta, A. (2022). An initial assessment of water security in Europe using a DEA approach. *Sustainable Technology and Entrepreneurship*, *1*. doi:10.1016/j.stae.2022.100002.

D'Inverno, G., Carosi, L., & Romano, G. (2021). Environmental sustainability and service quality beyond economic and financial indicators: A performance evaluation of Italian water utilities. *Socio-Economic Planning Sciences*, *75*, 100852. doi:10.1016/j.seps.2020.100852.

Dou, P., Zuo, S., Ren, Y., Rodriguez, M. J., & Dai, S. (2021). Refined water security assessment for sustainable water management: A case study of 15 key cities in the Yangtze River Delta. *China. Journal of Environmental Management*, *290*, 112588. doi:10.1016/j.jenvman.2021.112588.

European Environment Agency (2022). Available in: https://www.eea.europa.eu/data-and-maps Accessed on 13 March 2022.

FAO. 2022. https://www.fao.org/faostat/en/#home (Accessed 16 March 2022).

Guaita Martínez, J. M., Martín Martín, J. M., Ostos Rey, M. S., & de Castro-Pardo, M. (2020). Constructing knowledge economy composite indicators using an MCA-DEA approach. *Economic Research-Ekonomska Istraživanja*, *34* (1), 1–21.

Hatami-Marbini, A., Tavana, M., Saati, S., & Agrell, P. J. (2013). Positive and normative use of fuzzy DEA-BCC models: A critical view on NATO enlargement. *International Transactions in Operational Research*, *20*(3), 411–433.

Howlett, M. P., & Cuenca, J. S. (2017). The use of indicators in environmental policy appraisal: Lessons from the design and evolution of water security policy measures. *Journal of Environmental Policy & Planning*, *19*(2), 229–243. doi:10.1080/1523908X.2016.1207507.

Kenny, D. C., Costanza, R., Dowsley, T., Jackson, N., Josol, J., Kubiszewski, I., ... Thompson, J. (2019). Australia's genuine progressindicatorrevisited. 1962−2013 *Ecological Economics*, *158*, 1–10. doi:10.1016/j.ecolecon.2018.11.025.

Koronakos, G., Sotiros, D., Despotis, D. K., & Kritikos, M. N. (2021). Fair efficiency decomposition in network DEA: A compromise programming approach. *Socio-Economic Planning Sciences*, *79*, 101100.

Lafuente, E., Araya, M., & Leiva, J. C. (2020). Assessment of local competitiveness: A composite indicator analysis of Costa Rican counties using the 'Benefit of the Doubt'model. *Socio-Economic Planning Sciences*, *100864*. doi:10.1016/j.seps.2020.100864.

Marangoz, D., & Daloglu, I. (2022). Development of a water security index incorporating future challenges. In W. Leal Filho, & E. Manolas (Eds.), *Climate change in the Mediterranean and middle eastern region. Climate change management*. Cham: Springer. doi:10.1007/978-3-030-78566-6_15.

Mintrom, M., & Luetjens, J. (2017). Policy entrepreneurs and foreign policy decision making. *Oxford research encyclopedia of politics*.

Mu, W., Kanellopoulos, A., van Middelaar, C. E., Stilmant, D., & Bloemhof, J. M. (2018). Assessing the impact of uncertainty on benchmarking the eco-efficiency of dairy farming using fuzzy data envelopment analysis. *Journal of Cleaner Production*, *189*, 709–717.

OCDE. (2013). Framework of OECD work on environmental data and indicators. *Environment at a glance*. Paris: OECD Publishing. doi:10.1787/9789264185715-3-en 2013: OECD Indicators.

Omrani, H., Fahimi, P., & Mahmoodi, A. (2020). A data envelopment analysis game theory approach for constructing composite indicator: An application to find out development degree of cities in West Azarbaijan province of Iran. *Socio-Economic Planning Sciences*, *69*, 100675. doi:10.1016/j.seps.2018.12.002.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., ... Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, *54*, 438–447. doi:10.1016/j.envsci.2015.08.012.

Ruiz, F., & Cabello, J. M. (2021). MRP-PCI: A Multiple Reference Point Based Partially Compensatory Composite Indicator for Sustainability Assessment. *Sustainability*, *13 (3)*(1261). doi:10.3390/su13031261.

Scott, C. A., & Lutz-Ley, A. N. (2016). Enhancing Water Governance for Climate Resilience: Arizona,USA—Sonora, Mexico Comparative Assessment of the Role of Reservoirs in Adaptive Management for Water Security. *Water Resources Development and Management* (pp. 15−40). Springer.

Shen, Y., Ruan, D., Hermans, E., Brijs, T., Wets, G., & Vanhoof, K. (2011). Modeling qualitative data in data envelopment analysis for composite indicators. *International Journal of System Assurance Engineering and Management*, *2*(1), 21–30.

Verbunt, P., & Rogge, N. (2018). Geometric composite indicators with compromise benefit-of-the-doubt weights. *European Journal of Operational Research*, *264*(1), 388–401.

WRI (2022). Aqueduct water risk Atlas. Aqueduct project. Available in: https://www.wri.org/applications/aqueduct/water-risk-atlas/#/?advanced=false&basemap=hydro&indicator=w_awr_def_tot_cat&lat=30&lng=-80&mapMode=view&month=1&opacity=0.5&ponderation=DEF&predefined=false&projection=absolute&scenario=optimistic&scope=baseline&threshold&timeScale=annual&year=baseline&zoom=3 Accesed on January 2022.

Eurostat (2022). Available in: https://ec.europa.eu/eurostat/data/database. Accessed on 14 March 2022.

Yao, L., Shuai, Y., & Chen, X. (2020). Regional water system vulnerability evaluation: A bi-level DEA with multi-followers approach. *Journal of Hydrology*, *589*, 125160. doi:10.1016/j.jhydrol.2020.125160.

Yee, S. H., Carriger, J. F., Bradley, P., Fisher, W. S., & Dyson, B. (2015). Developing scientific information to support decisions for sustainable coral reef ecosystem services. *Ecological Economics*, *115*, 39–50. doi:10.1016/j.ecolecon.2014.02.016.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*, 338–353.

Zhao, S., Liu, W., Zhu, M., Ma, Y., & Li, Z. (2021). A priority-based multi-objective framework for water resources diversion and allocation in the middle route of the South-to-North Water Diversion Project. *Socio-Economic Planning Sciences*, *78*, 101085.