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A multi reference point based index to assess and monitor European water policies from a sustainability approach

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ABSTRACT

The scarcity of water resources is a serious problem that concerns governments and international institutions. The importance of water resources and the expectations of billions of people with serious water shortages and subsequent food shortages have made European water policy makers focus all their attention on the sustainability of water as a resource. In this paper we propose a new Water Sustainability Indicator based on a Multi-Reference methodology (WSI-MR) which permits modeling compensation between the analyzed criteria and provides a participative approach. The WSI-MR provides results based on 19 variables grouped into 5 dimensions: availability, access, resilience, good governance and economic capacity. The indicator was applied to assess water sustainability in 27 European countries. The results showed that Finland, the Netherlands, Sweden and the United Kingdom obtained the best global results in terms of weak water (compensatory) sustainability. Using a non-compensatory approach, no country gained acceptable results in terms of strong sustainability. Some subdimensions related to climate change and the state of freshwater resources were detected as especially vulnerable in all the analyzed countries. Finally, the study identified some eastern European countries with low GDP and good performance of availability and cost of water, where bad results in terms of governance and water productivity could jeopardize water sustainability in the event of a potential economic development, if these limitations are not addressed. In a context of economic and political instability, due to the current armed conflict in nearby countries such as Ukraine, it is especially important to pay attention to these countries, whose good governance indicators could worsen even more. The proposed indicator is useful to identify warning signs and can contribute to the improvement in decision-making processes and to monitoring international water policies.

1. Introduction

As a resource, water is considered a common property, but as a public service it is considered a commodity. This has meant that Europe has outlined a dual orientation in water policies, keeping the public-private debate on water use and management alive for decades. Today, the importance of water resources means that public entities prioritise the environmental paradigm. The actions of these institutions take the form of multiple services provided under different public-private cooperation formulas [1]. In this sense, at present, the concept of water sustainability is acquiring indisputable prominence. The concept of sustainability began to be outlined in the 1970s and 1980s. Examples of initiatives contributing to its positioning include the United Nations Conference on the Human Environment, which raised global environmental awareness [2] and the World Conservation Strategy [3], which included the concept of sustainable development for the first time. These conferences inspired the Brundtland Report [4], which marked a strong commitment to the integration of sustainability into international policies at a global level. Sustainable development was defined in the Brundtland Report as " … development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [4]. While the Brundtland Report focused on the need to secure intergenerational resources in a relatively broad manner, subsequent definitions of sustainable development increasingly focused on addressing environmental, social and economic issues as a whole, based on the well-known "triple bottom line

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approach" principle of sustainability [5,6]. [7] added a fourth element associated with institutional indicators, namely participation, gender balance and justice. These four dimensions of sustainability, environmental, social, economic and institutional, have been accepted by the international scientific community and now form the basis of a rich and extremely complex concept of sustainability.

The accelerated decline in biodiversity and the rapid degradation of environmental services in recent decades has generated great scientific and social concern for sustainable development [8], which has led to the launch of numerous initiatives led by international organisations. Some examples are the Sustainable Development Goals Project (SDG), promoted by the United Nations [9] and 2030 Agenda for Sustainable Development, promoted by the Organization for Economic Co-operation and Development [10]. These organisations continuously monitor the efforts made by countries to promote sustainable development [11] and to this end; they usually use composite indicators (CIs). In this sense, the usefulness of CIs is essential to assess and monitor sustainability achievements in a rigorous manner. Some authors have developed general sustainability indices, such as the Environmental Sustainability Index [12], the Barometer of Sustainability [13] and Pressure-State-Response (PSR) based sustainability indicators [7] and the Sustainability Indicator Systems [7]. Other authors have proposed sustainability CIs focused on a specific field, such as agriculture [14], the environment [12], fossil fuel [15] and water [16–18]. However, if measuring sustainability in general terms is a complex process, measuring the sustainability of water resources is particularly complicated and increasingly necessary. Human dependence on freshwater resources, the current global water crisis and the complexity of water resource management are attracting strong interest from governments and international institutions. The development and implementation of international policies also requires the development of rigorous tools to measure progress, monitor and make decisions [19].

From an economic and social perspective, humanity depends on water not only for drinking, but also for food production, waste treatment, energy production and transport, to name a few examples [20]. From an ecological perspective, water as an integral component of all ecosystems is the support that ensures health and the conservation of biodiversity. The importance of water as a resource is facing an unprecedented global freshwater crisis that threatens its present and future supply for humans. Although about 70% of the earth's surface is covered with water, only 2.5% of the world's freshwater is suitable for human consumption. This small proportion of freshwater is the engine of human health, the global economy and the well-being of societies in the broadest sense. Unfortunately, the world has failed to manage its water resources sustainably. Over the past century, available freshwater resources have come under increasing pressure, as extraction rates have increased almost six-fold. In 2014, the average global availability of renewable freshwater was about 40% less than in the 1970s. Moreover, freshwater resources are unevenly distributed around the world, suffer from strong seasonality, and as global demand for water continues to grow, available resources are further depleted [21].

On the other hand, managing water resources is particularly challenging. The scarcity of water as a resource, the protection of many sites with aquatic ecosystems and the complexity associated with the management of large watercourses have traditionally led to strong conflicts over their management. These conflicts can block decision-making processes and even lead to armed conflicts between countries [22]. Complexity increases substantially when management involves multiple jurisdictions or countries. Although there are international regulations governing the protection and use of watercourses in transboundary locations and international lakes (such as the EU Water Framework), as well as specific bilateral cooperation agreements, at the operational level stakeholders must also decide on maintenance, implementation and evaluation programmes [23]. This implies that decisions taken are not isolated events but are part of a continuous decision-making process over time. The global water crisis and the complexity of water management are two issues of growing concern and are increasingly present in European policies. The EU Water Framework Directive (2000/60/EC; December 22, 2000, OJ L 327) is a guide for the new European water policy [90]. The novelty of this framework is an integrated approach, which is stronger than the fragmented water policy initiatives of the past. This approach is based on a number of key objectives such as attaining good quality for all water within a set timeframe, defining a combined approach to emission limit values and quality standards, extending the scope of water protection to all water, both surface and groundwater, promoting river basin-based water management, obtaining the right price, involving citizens more, and promoting streamlined legislation.

In this context, the development of rigorous but flexible CIs, which make it possible to measure the quality, progress and compare water sustainability from a participatory and inclusive approach, is particularly useful for the successful development of European public policies and to facilitate decision-making processes or even channel negotiation processes. In addition, two elements are vital when facing the task of constructing these composite indicators. On the one hand, it is imperative that the resulting measure does not mask the possible underperformance of each country with respect to certain individual indicators. Therefore, in addition to a more traditional compensatory measure, a non-compensatory measure that highlights these poor performances is needed which can also be used to make concrete decisions for improvement. On the other hand, given that the concept of what is sustainable and what is not depends both on the environment under study and on evolution over time, it is important to develop a methodology that permits the use of reference levels to establish different levels of performance.

Taking all of the above into account, the objective of this paper is twofold: on the one hand, to present a composite indicator, the WSI-MR, which uses a participatory approach, allowing for flexible compensation and is built through sequential aggregation. And on the other hand, to present an application of the index to measure water sustainability in 27 European countries from both a weak sustainability approach and a strong sustainability approach.

The proposed index permits the flexible measurement of countries' water sustainability using different degrees of compensation sequentially at different levels of aggregation and establish reference levels for the indicators. With respect to the reference levels used, statistical levels have been chosen and, therefore, the results obtained reflect the relative position of each country, as compared to the rest of the countries considered. More precisely, in order to split the statistical space into three equal parts, the 33rd and 66th percentiles of all available values have been taken for each indicator, in addition to the minimum and maximum values, as reference levels. The methodology also provides the possibility to integrate the assessments of multiple decision-makers simultaneously and, on the other hand, to provide a ranking of 27 European countries in terms of water sustainability. The multiple benchmark method used (MRP-WSCI [24], has already been successfully applied in other areas of sustainability measurement (see, e.g., Refs. [25–30].

The structure of the paper is as follows. Section 2 describes the difficulties associated with the development of water sustainability composite indicators and presents a review of the literature on these, section 3 describes the proposed methodology for the design of the WSI-MR, section 4 presents the results of the application of the WSI-MR to 27 European countries and section 5 provides a discussion of these results. Finally, section 6 provides some concluding remarks.

2. The challenge of assessing water sustainability

The use of CIs has become particularly relevant in the description of complex realities involving numerous variables [31–33]. These indicators represent an overview derived from a group of partial indicators, avoiding comparison based on multiple individual data. The interest in these CIs lies in their ability to synthesise information and provide a useful tool for decision-making [34], as the aggregation of information into a single variable allows for a simpler interpretation of the phenomenon and makes it possible to represent the performance of regions and countries [35]. This approach is very useful for policy makers, academics, analysts, etc., as they can analyze a phenomenon on the basis of a single piece of data [36]. In this sense, the use of CIs is particularly useful to measure the concept of water sustainability, due to its multidimensional character [37], as well as the importance and growing interest in this phenomenon at international, national and local levels. Indeed, while CIs have traditionally been used to quantify risks, monitor change and measure progress, they are increasingly used to plan the sustainable use of water resources [38]. The main advantage of using composite indicators to measure water sustainability, with respect to simple indicators, lies in their ability to provide a global assessment that simultaneously contemplates the different elements that integrate each of the dimensions that make up sustainability, i.e., the ecological, economic, social, and institutional dimensions [39,40]. Scores associated with one or several simple unaggregated indicators may provide adequate ratings to measure each item separately, however, they are not able to adequately measure the concept of water sustainability. For example, a country could record very good scores for its water resources availability, but very poor scores for its degree of resource exploitation and water productivity. In this case, even if the current water availability in that country were good, there would probably be serious problems in maintaining the availability of water resources in the medium term. In this case, CIs could provide more appropriate results to measure water sustainability, compared to a battery of simple indicators. In addition, the way of aggregating the different components of the CI can provide very interesting intermediate results, useful for public policy making.

In CI design there is a common procedure disaggregated into six elements: selection of components and dimensions, calculation of sub-index values, weighting, aggregation, calculation of a final index value, and assessment of the robustness of the indicator [37]. [41] stressed the importance of normalisation, weighting and aggregation processes in the design of sustainability indicators. Weighting and the definition of weights is important in the design of CIs as it can condition their final result. Equal weighting is the most common procedure in the development of CIs [42]. This weighting scheme may be perceived as "neutral", but it is not, since not all the variables considered assume the same importance, conditioning the final scores (Fernández et al., 2020). Thus, equal weighting misses the point of differentiating between essential indicators and less important indicators, treating them all in the same way [42]. On the other hand, when there is a non-homogeneous hierarchy in the design of CIs, for example, when several dimensions are defined with different numbers of indicators, and weights are distributed equally dimension-wise, single indicators do not necessarily receive equal weights [43]. In addition to the values assigned to the weights, the weighting process can be individual, stochastic or participatory. In individual weighting, the weights are determined by the analyst based on his or her prior knowledge and/or studies. This weighting scheme is usually the most common as it is very easy to apply [43]. Stochastic weighting processes determine weights using simulation methods or probabilistic models. Weighting based on participatory methods captures the weights determined by various decision-makers, who may be experts, interest groups or the general public. This participatory approach had a boom in the development of models for analysing water sustainability between 2000 and 2009, although since then it has become less relevant [19]. The major limitation of these methods is associated with the large number of economic resources and time they require, although they are particularly suitable for dealing with conflictual issues such as water management. In the design of CIs that consider the participation of several decision-makers, the aggregation process is twofold: it is necessary to aggregate the valuation of each participant and it is necessary to aggregate the simple indicators into a single CI.

The aggregation process is another key element in the construction of CIs and is closely linked to compensability issues [44]. The issue of compensability refers to whether in the aggregation process, the poor performance of one of the simple indicators can compensate for the good performance of another, or not. When compensability is not allowed, then the poor performance of the simple indicators is transferred to the poor performance of the composite indicator. When compensation is absolute, poor performances of simple indicators are compensated by good performances of others [41]. Linear aggregation schemes consider a fully compensatory approach, as well as some multi-criteria techniques such as SMART, TOPSIS, DEA and UTA [41]. Most sustainability indicators consider aggregation methods based on total compensation, such as the weighted sum or an arithmetic mean. On the other hand, some multi-criteria techniques such as ELECTRE and PROMETHEE use a non-compensatory scheme, although these techniques are not very popular due to the complexity of their application [42]. In this sense, methods based on multiplicative schemes, such as geometric means and some utility-based methods, such as MAUT and MAVT allow for mixed compensation. Other models have been specifically designed for partial compensation in CI design, such as the Mazziotta-Pareto Index [91], the Penalty for a Bottleneck method [45], the Mean-Min Function [46] and the Directional Benefit-of-the-Doubt (BoD) method [47]. The double reference point methodology was initially designed to measure sustainability [25] and subsequently a generalised version allowing the use of multiple references was presented [24]. This multi-reference partial offset approach provides twofold flexibility: to determine reference levels and to define desired offset levels. Despite the frequent use of aggregation methods based on total compensation to measure water sustainability, it is very interesting to be able to model the compensation and obtain values associated with strong or weak water sustainability [48]. However, aggregation techniques based on flexible trade-offs have been little used to date to measure water sustainability.

Considering the measurement of sustainability, the degree of trade-off between indicators can be closely related to the strong and weak sustainability approaches. The discussion between strong and weak sustainability started in the 1990s, with the proposal of a weak sustainability index by Ref. [49]. According to the notion of weak sustainability, an economy is considered sustainable if its savings rate is greater than the combined depreciation rate of natural and man-made capital. In other words, *sustainability* is equivalent to the non-decline of the total capital stock. From a broader perspective, the weak sustainability approach can be seen as a more "permissive" approach than the strong sustainability approach. In this line, CIs based on flexible trade-off schemes can be very useful tools for public policy decision-making processes. Thus, by adopting a total trade-off approach, the indicator provides a weak measure of sustainability, as it assumes the acceptance of some bad values as long as there are other values that are good enough to compensate for them. On the other hand, with a non-compensatory approach, the acceptance of bad values is not admissible in any case and therefore the indicator provides a strong measure of sustainability. Some works, such as [41,50] have proposed different methodologies for the design of sustainability indicators capable of differentiating between both types of sustainability [50]. assessed the sustainability of socioeconomic growth in Inner Mongolia between 1987 and 2015 considering energy consumption, and food and water footprints, and measured the different types of sustainability by assigning different weights to environmental, economic and social dimensions [41]. proposed a more sophisticated composite index based on flexible trade-off schemes to measure strong and weak sustainability in different contexts.

In general, the construction of composite indicators can naturally be considered as a multi-criteria decision problem, in which the different individual indicators play the role of criteria to be considered. This is why a large number of the methods discussed above are more or less direct applications of well-known multi-criteria methodologies. In this regard, a survey of multi-criteria methodologies applied to the calculation of composite indicators can be found in Ref. [51]; which refers to the different aspects mentioned (weights, normalisation, compensability, etc.) for the methods analyzed. Due to their importance, the literature review on WSCI has focused on three points: weighting schemes, participative approaches and compensation schemes, as described in Table 1. Most of these CIs use full compensation schemes that do not consider a participatory approach. The Water Poverty Index [16], Water Sustainability through Decision Analysis [55], the Aquifer Sustainability Index [56], the Sustainable Groundwater Resources Index (Bui et al …, 2019), the Water Management Sustainability Index [60] and the Groundwater Sustainability Index [61] use a full compensation approach to aggregate the sub-indices, by using an arithmetic aggregation method, typically a weighted mean or sum. Of these [56,59], and Singh and Bakhar (2017) considered the involvement of multiple decision-makers in some way. All three papers were concerned with measuring groundwater sustainability. The former used an Analytic Hierarchy Process (AHP) to measure sustainability as measured with the traditional three pillars (environmental, economic and social) of groundwater in Hanoi from three approaches: water quality, quantity and management. The latter used a Pressure-State-Response scheme and collected four dimensions: hydrogeology, environment, life and policy to measure the sustainability of aquifer management in data-poor semi-arid areas. In this case, it is proposed that the weights for each indicator be defined by consensus among various stakeholders in the basin. Singh and Bakhar (2017) used an arithmetic approach to aggregate simple indicators to measure groundwater sustainability considering five dimensions: groundwater resources, ecosystem health, availability of infrastructure, human health and competence. Similarly [59], used AHP to determine the expert weights [17]. also used a Pressure-State-Response scheme integrating hydrology, environment, life and policy (H-E-L-P) issues into a single CI to measure water sustainability at a basin level. This CI incorporates several components of the Human Development Index (HDI) and their way of aggregating the sub-indices is also an average [16]. proposed a Water Poverty Index based on five dimensions (resources, access, capacity, use, and environment) and eighteen indicators. They used equal weights and an average to calculate the final value [53]. proposed an alternative Water Poverty Index, using a gap method. Specifically, it considered four components: ecosystem health, community well-being, human-health and economic welfare. The Canadian Water Sustainability Index also included vulnerability in the CI through this dimension, including five dimensions: resource, infrastructure, human health, capacity and ecosystem health. This index aggregated the sub-indices using an average [60]. developed a Water Management Sustainability Index and applied it to measure the sustainability of 969 sub-basins in Mexico. They used an additive aggregation scheme to include four sub-systems: environmental, social, economic and institutional [55]. also followed an additive scheme to aggregate water resource, water demand and water policy dimensions, but incorporated a novelty; they determined the weights using a stochastic approach. Other indicators, such as the Long-term Water Resources Management Model [52], the Sustainability Index for Water Resources Planning and Management [18], the West Java Water Sustainability Index [57] and the Sustainability Index for Water Resources Planning and Management-extension [58] used partial trade-off approaches when aggregating the sub-indices [18,58,61]. used a geometric mean to calculate the final value of the CI [18,58]. developed a CI aimed at measuring sustainable water management from three performance indices: reliability, resilience and vulnerability [58]. proposed an extension of the first one, considering two additional performance indicators: reliability of annual firm (safe) water as a system yield and deviation of reservoir levels from corresponding rule curves, to compute and use the CI [57]. used a multiplicative aggregation scheme. They used three dimensions (conservation, water use, policy and governance) and nine simple indicators to measure three water catchments in Indonesia. They used a participatory approach to determine the selection of components with a panel of experts through the Delphi method [52]. is the only index that considered a partial compensation scheme to determine water sustainability CI using 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 and economic acceptability). This model does not consider a participatory approach, as the weighting scheme is determined by the analyst.

The indicator proposed in this paper has several strengths: it permits

Table 1
Water sustainability CI studies, weighting scheme, participative approach and compensation scheme.

Composite Indicators	Weighting scheme	Participative approach	Compensation scheme*
Long-term Water Resources Management Model [52]	Defined by the analyst	No	Partially (distance-based programming)
Water Poverty Gap [53]	Defined by the analyst	No	Full (arithmetic)
Water Poverty Index [16]	Equal weight	Yes (component selection) (stakeholders and experts)	Full (arithmetic)
Watershed Sustainaility Index [17]	Equal weight	No	Full (arithmetic)
Canadian Water Sustainability Index [54]	Equal weight	Yes (component selection) (workshop)	Full (arithmetic)
Sustainability Index for Water Resources Planning and Management [18]	Based on annual water demand	Yes (weighting) based on annual water demand by water user groups	Partially (geometric)
Water Sustainability through Decision Analysis [55]	Stochastic approach (equal and arbitral)	No	Full (arithmetic)
Aquifer Sustainability Index [56]	Equal weight	Partially (component assessment) (consensuses between stakeholder groups to assess public participation)	Full (arithmetic)
West Java Water Sustainability Index [57]	Equal or non-equal weights	Yes (component selection) (Delphi method with stakeholders)	Partially (geometric)
Sustainability Index for Water Resources Planning and Management -extension [58]	Based on annual water demand	Yes (weighting) (annual water demand by water user groups)	Partially (geometric)
Sustainable Groundwater Resources Index [59]	Determined by pairwise comparisons by AHP	Yes (weighting) (experts)	Full (arithmetic)
Water Management Sustainability Index [60]	Determined by Factor Analysis/ Principal Component Analysis	No	Full (arithmetic)
Groundwater Sustainability Index [61]	Determined by pairwise comparisons by AHP	Yes (weighting) (experts)	Full (arithmetic)

the use of reference levels to express results according to the position of each country with respect to these levels, it provides a measure of strong and weak sustainability at different levels of aggregation according to different compensation schemes, it permits early warning signals to be identified for each country, it permits vulnerable dimensions to be identified, and it also permits a participatory approach to measurement.

The studies listed in Table 1 have undoubtedly made important contributions to the goal of quantifying water sustainability. However, to date, no indicator aimed at measuring water sustainability has proposed a flexible compensation scheme, such as the one proposed in this study. The proposed model, in addition to providing global and semi-global results, depending on the degree of compensation, allows integrating the preferences of different decision-makers and uses a sequential aggregation method. The novelty of this study lies in the ability of the proposed index to measure water sustainability from this simultaneous approach of participation, flexible compensation and sequential aggregation. The participation of different decision makers can help mitigate potential conflicts between stakeholders or even between countries, while integrating a greater source of knowledge into the process.

The flexible compensation approach allows different measures of water sustainability to be calculated. These approaches include weak sustainability approaches (providing a less demanding overall result, as full compensation between indicators is allowed), as well as others inspired by strong sustainability (providing a more demanding overall result, as compensation between indicators is not allowed). The type of approach is linked to the degree of compensation allowed between indicators and/or dimensions or sub-dimensions. Finally, sequential aggregation allows for early identification of potential problems. From a water security perspective, this is particularly useful, since the detection of difficulties could prevent situations of extreme drought with no return in the analyzed countries.

3. Material and methods

3.1. Selection of dimensions and variables

A total of 5 dimensions, 13 sub-dimensions and 19 simple indicators were identified to construct the WSI-MR (Table 2). To determine the dimensions, the definition of “Water resources sustainability” by Ref. [62] was followed, which refers to the capacity to provide and manage a sufficient quantity and quality of water to meet present human and ecosystem needs, without compromising the needs of future generations. This definition implicitly considers elements associated with dimensions 1–4 (Availability, Access, Resiliency and Reliability). On the other hand, the approach of [7] was also followed, which considers the institutional component as a key element of sustainability, serving as a link between its three traditional pillars (environmental, social and economic). Along these lines, dimensions 5 and 6 (Good governance and Economic capacity) were defined. Water vulnerability is integrated into the analysis through dimension 3-Resilience.

Dimension 1. Availability. Water availability is captured through two sub-dimensions: Capacity and State. Capacity comprises the quantity of available water resources and State refers to the quality of these resources. In addition, the ability of the available water demand to meet the actual water demand is considered [18,52,63]. and [58] highlighted the importance of this characteristic to measure the sustainability of water resources [87].

Dimension 2. Access. Access to water resources is present in most water sustainability CIs. This dimension largely captures the essence of one of the Millennium Development Goals; SDG-6. “Ensure availability and sustainable management of water and sanitation for all” [64]. This target comprehensively covers all aspects of both the water cycle and sanitation systems. Its scope is designed in a cross-cutting manner, so that it can contribute to the achievement of other SDGs, especially in environment, health, economy and education. Along these lines, three

Table 2
Dimensions, sub-dimensions, indicators, years, type and source.

Dimension	Sub-dimension	Indicators and units	Years	Type	Source
DIMENSION 1. AVAILABILITY	1.1. Capacity	1.1.1. Renewable freshwater resources per inhabitant	2007–2017	+	Eurostat
		1.1.2. Water exploitation index (%)	2000–2017	−	EEA
	1.2. State (Ecological status)	1.2.1. Surface water bodies. Ecological status or potential High and Good (% of High and Good water bodies)	2021	+	EEA
		1.2.2. Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (%)	2000–2018	−	European Environment Agency (EEA)
DIMENSION 2. ACCESS	2.1. Drinking water	2.1.1. Proportion of population using safely managed drinking water services (%)	2010–2018	+	Eurostat
	2.2. Population’s access to water	2.2.1. Population connected to at least secondary wastewater treatment (%)	2007–2017	+	Eurostat
DIMENSION 3. RESILIENCE	3.1. Climate change	3.1.1. Greenhouse gas emissions (in CO_2 equivalent) (tonnes per capita)	2000–2018	−	EEA
		3.1.2. Greenhouse gas emissions intensity by energy (index, 2000 = 100)	2010–2017	−	EEA
		3.1.3. Contribution to the international 100bn USD commitment on climate related expending (euro per inhabitant)	2014–2017	+	EIONET
	3.2. Erosion-Watershed state	3.2.1. Estimated soil loss by water erosion by land cover type (tonnes per hectare)	2000–2016	−	Eurostat
		3.2.2. Share of land cover types affected by severe erosion (%)	2000–2017	−	Eurostat
	3.3. Groundwater available	3.3.1. Groundwater abstraction (m^3 per inhabitant)	2007–2017	−	EEA
	3.4. Protection of freshwater ecosystems	3.4.1. Average proportion of Freshwater Key Biodiversity Areas (KBAs) covered by protected areas (%)	2000–2019	+	Eurostat
DIMENSION 4. GOOD GOVERNANCE	4.1. Social cohesion	4.1.1. Income inequality. Gini Index	2008–2019	−	Eurostat
	4.2. No corruption	4.2.1. Corruption Perception Index (score: worst 0–100 best)	2012–2019	+	Transparency International
	4.3. Performance of water sustainability policies	4.3.1. Environmental performance index (sanitation and drinking water) (score: worst 0–100 best)	2020	+	EPI
		4.3.2. Environmental performance index (water resources) (score: worst 0–100 best)	2020	+	EPI
DIMENSION 5. ECONOMIC CAPACITY	5.1. Cost of water	5.1.1. Annual Estimated Tariff based on a consumption of $15m^3$ per month ($/m3)	2020	−	IBNet DB
	5.2. Water productivity	5.2.1. Water productivity (Euro per cubic meter (Euro: chain-linked volumes, reference year 2010, at 2010 exchange rates))	2000–2018	+	Eurostat

sub-dimensions associated with the availability of drinking water, wastewater treatment and access to water for the population were defined.

Dimension 3. Resilience. Resilience represents the capacity of systems to adapt to changing conditions [65] and represents the vulnerability of water. To capture the resilience of freshwater systems, four sub-dimensions were defined: Climate change, Erosion-watershed state, Groundwater available and Protection of freshwater ecosystems. These sub-dimensions include elements associated with the fight against climate change, the erosion of river basins, the depletion of aquifers and the protection of freshwater aquatic ecosystems [88].

Dimension 4. Good governance. More recent definitions of sustainability have added to the three basic pillars (environmental, economic and social) another element that serves as a link between them and ensures that they can be realised: an institutional or governance component [7]. The difficulty of integrating social and economic elements into natural resource conservation has been much debated. However, it seems that when a minimum of good governance is ensured, communities are able to organise themselves efficiently to conserve environmental resources [66]. In this sense, it seems essential to integrate a dimension that considers an institutional component to ensure that the other three dimensions are possible. This dimension comprises three sub-dimensions: Social cohesion, No corruption and Performance of water sustainability policies. All of them include elements that favour social conditions associated with social equality, institutional quality and compliance with rules [89,92].

Dimension 5. Economic capacity. Finally, a dimension that has not been taken into account to date in any WSCI was included, which directly affects the economic dimension and the water sustainability of countries. This dimension represents a country's capacity to meet the cost of water and considers two sub-dimensions associated with the price of available and accessible water [67] and a country's water productivity. This is understood to be the efficiency of water use in generating economic outputs per unit of water used [77].

3.2. Databases and data preparation

The data was collected from global and European databases such as the Environmental Performance Index, European Environment Agency, Eurostat, The European Environment Information and Observation Network (Eionet), the Organization for Economic Co-operation and Development (OECD), Transparency International, United Nations and World Resources Institute. The data used do not have a homogeneous temporal distribution. For some indicators there are time series that range from 2007 to 2018, while for others there are only values in one or two years. For this reason and given that the purpose of this study is to compare the performance of the countries analyzed in terms of water sustainability, the average data of the series available in each indicator, for the countries analyzed, in the time period considered, were used. Once the data was constructed in this way, only 0.58% of missing values were detected for indicators 2.2.1. (Cyprus), 3.3.1. (Austria) and 5.1.1. (Ireland). In all these cases, the missing values were replaced by the worst values of the respective series, in order to penalize the lack of information.

Subsequently, the following outlier detection and treatment process was followed. For each indicator i, the mean (m_i) and standard deviation (d_i) of all available data in the corresponding time series were calculated. Any value outside the range $[a_i, b_i]$ was considered an outlier, where:

$$a_i = m_i - 2\cdot d_i, b_i = m_i + 2\cdot d_i$$

Finally, if we call x_{ij} the value of indicator i for country j and x_{ij} is considered an outlier, a new value $\underline{x}_{ij}$ is assigned to it as follows:

$$\underline{x}_{ij} = \begin{cases} a_i & if \quad x_{ij} < a_i \; b_i \quad if \quad x_{ij} > b_i \end{cases}$$

with this procedure, we avoid possible distortions caused by outliers at the extremes of the scale used in the reference point method, which is described below.

3.3. The multiple reference point methodology

The WSI-MR methodology used in this study is an adaptation of the case of water sustainability of the multiple reference point method for constructing composite indicators (MRP-WSCI, [24]. This methodology consists of three phases: establishment of the weights, establishment of the reference levels and successive aggregations, which we detail in the following subsections.

3.4. Weighting of dimensions and sub-dimensions

As detailed in Table 2, the system of water sustainability indicators used in this study are grouped into dimensions and sub-dimensions. Regarding the weights, it was decided to assign equal weights to the simple indicators of each sub-dimension, since there are few indicators per sub-dimension and weighting them would imply an overly demanding process, which would not have a significant impact on the final solutions. On the other hand, the weights associated with the dimensions and sub-dimensions were identified through a participatory process in which the evaluations of a panel of experts were collected. To this end, each expert was individually provided with a questionnaire structured in 6 blocks with a total of 18 questions. The first block shows the relative importance of the 5 dimensions, while blocks 2–6 show the relative importance of the sub-dimensions included in each dimension. The questions were designed to assess the relative importance of each item on a Likert scale from 0 to 10, where 0 is "Not at all important" and 10 is "Extremely important". In addition, in order to facilitate the work of the experts, the questionnaire was supplemented with information on the main descriptive statistics of the available time series for each indicator: unit of measure, mean, standard deviation, maximum and minimum, and a graph of the time series.

Once the information from the different experts was collected, group weights were obtained using the preference aggregation methodology described in Ref. [68]. This methodology is based on the Meta-Goal Programming algorithm [69] and it simultaneously optimizes various achievement functions that measure the deviations of the group weights with respect to the individual weights of the experts:

- The maximum individual deviation.
- The maximum aggregate deviation per expert.
- The maximum aggregate deviation per indicator.
- The aggregate total deviation.

Taking the values of these achievement functions for the geometric mean of the individual evaluations as references, it is possible to improve one or several of these measures, without worsening any other, both for the weights of the sub-dimensions and for those of the dimensions (see Appendix 1 and [68]; for further details).

3.4.1. Reference levels

In order to obtain measurements that indicate the relative position of each country with respect to all the countries in the sample, the 33rd (q_i^1) and 66th (q_i^2) percentiles of all available values were taken for each indicator i, in addition to the minimum (q_i^0) and maximum (q_i^3) values, as reference levels. It must be noted that these values are calculated once the outliers' treatment described in subsection 3.2 has been carried out. This implies the use of three performance levels. For an indicator of the type the more the better, a country with a value between the minimum and the 33rd percentile would be in the low level, one with a value between the 33rd and 66th percentiles in the medium level, and one with a value above the 66th percentile would be in the high level. Once the reference levels for the indicators were established, the achievement scalarizing function allows all the indicators to be measured on a common scale. For an indicator of the type the more the better, this function takes the following form, assuming that x_{ij} is the value of indicator i for country j (or the corresponding modified value, should x_{ij} be an outlier):

$$s_i(x_{ij}) = \begin{cases} \frac{33}{q_i^1 - q_i^0}(x_{ij} - q_i^0) & \text{if } q_i^0 \le x_{ij} \le q_i^1 \\ 33 + \frac{33}{q_i^2 - q_i^1}(x_{ij} - q_i^1) & \text{if } q_i^1 \le x_{ij} \le q_i^2 \\ 66 + \frac{34}{q_i^3 - q_i^2}(x_{ij} - q_i^2) & \text{if } q_i^2 \le x_{ij} \le q_i^3 \end{cases}$$

Thus, the achievement function s_i produces values on the common scale 0-33-66-100. Specifically, s_i takes a value between 0 and 33 if the indicator value is below the corresponding 33rd percentile, a value between 33 and 66 if the value is between the 33rd and 66th percentiles, and a value between 66 and 100 if the country has a value above the 66th percentile in the indicator.

3.4.2. First aggregation: from single indicators to sub-dimensions

The first level of aggregation consists of constructing two composite indicators (a weak or fully compensatory one and a strong or non-compensatory one) for each country and for each sub-dimension. Let us consider a given sub-dimension k and let us assume that it contains I single indicators. Given that equal weights are used at this aggregation level, the composite indicators are built as follows:

- Weak composite indicator of country j for sub-dimension k:

$$W_j^k = \frac{1}{I}\sum_{i=1}^{I} s_i(x_{ij})$$

- Strong composite indicator of country j for sub-dimension k:

$$S_j^k = \{s_i(x_{ij})\}$$

W_j^k is the mean of the achievement functions of country j for all the indicators of the sub-dimension and therefore measures the overall performance of the country in said sub-dimension. On the other hand, S_j^k shows the value of the worst achievement function, so it indicates the weakest indicator of the entire sub-dimension for country j. It is important to keep in mind that the composite indicators take values on the same scale as the achievement functions. Therefore, W_j^k can be interpreted as the global position of the country with respect to the percentiles used in all the indicators of the sub-dimension. On the other hand, S_j^k indicates the position of the worst indicator. For example, if 33 $< S_j^k < 66$, it means that at least one indicator of the sub-dimension is in the middle level and there are none in the low level. In this way, as discussed in Ref. [70]; the joint consideration of the weak and strong composite indicators provides valuable complementary information for the analysis of the countries.

3.4.3. Second aggregation: from sub-dimensions to dimensions

According to Table 2, the system of indicators is organized in dimensions and subdimensions. Once the composite indicators of ach subdimension have been obtained in section 3.3.3, another aggregation has to be carried out to get the composite indicators of each dimension. As the composite indicators of the sub-dimensions take values on the same scale 0-33-66-100, they can be used as achievement functions at this next level of aggregation. In this case, in addition, we have weights for each sub-dimension, obtained as described in 3.3.1 (the weights obtained ban be seen in Fig. 1). Let us assume that we wish to obtain the composite indicators for dimension d, which has K sub-dimensions and let us denote by μ_k, $(k = 1, \ldots, K)$ the weights of each sub-dimension. If we consider the weak composite indicators of the sub-dimensions, we can now build the following composite indicators for each country and each dimension:

- Weak-Weak composite indicator of country j for dimension d:

$$WW_j^d = \sum_{k=1}^{K} \mu_k^w W_j^k,$$

where:

$$\mu_k^w = \frac{\mu_k}{\sum_{l=1}^{K}\mu_l}$$

- Strong-Weak composite indicator of country j for dimension d:

$$SW_j^d = \{\widehat{W}_j^k\}$$

where:

$$\widehat{W}_j^k = \alpha^t + \left(W_j^k - \alpha^t\right)\mu_k^s, \text{if } W_j^k \in \left[\alpha^{t-1}, \alpha^t\right], (t = 0, 1, 2, 3),$$

$$\alpha^0 = 0, \alpha^1 = 33, \alpha^2 = 66, \alpha^3 = 100; \quad \mu_k^s = \frac{\mu_k}{\{\mu_l\}}$$

WW_j^d reflects the global performance (through a weighted and therefore,

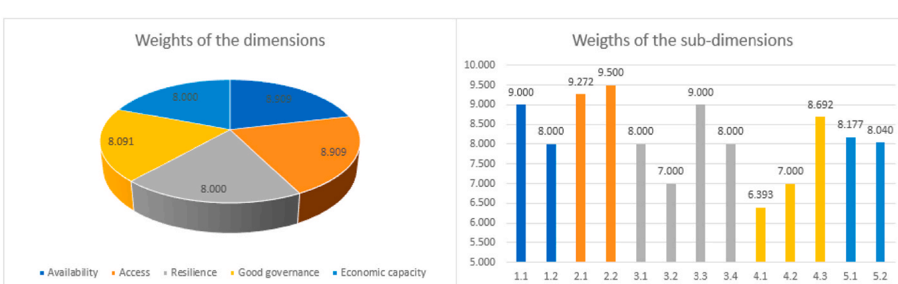

Fig. 1. Group weights for the dimensions and sub-dimensions. The dimensions and sub-dimensions, as well as the numbering of the latter, follow the scheme shown in Table 2.

compensatory average) of country j in dimension *d*. SW_j^d indicates the worst sub-dimension of country *j* within dimension *d*, shaded by its weight. That is, it is considered worse if the worst behavior takes place in a higher weighted sub-dimension. In any case, SW_j^d is designed so that it takes the value in the sub-interval (0-33-66-100) where the worst value of the dimension is found (see Ref. [24]; for more details). Therefore, regardless of the weights, a value of, for example, 40 in SW_j^dindicates that no sub-dimension of the country is in the low level and at least one is in the medium level.

If we consider the strong composite indicators of the sub-dimensions, we can build another interesting composite indicator for each country and each dimension:

- Strong-Strong composite indicator of country *j* for dimension *d*, SS_j^d, which is constructed the same as SW_j^d, but considering S_j^k instead of W_j^k. This composite indicator drags the worst individual indicator of country *j* in dimension *d*, nuanced by the weights of the sub-dimensions, as discussed above.

3.4.4. Third aggregation: from dimensions to global composite indicators

Following the same philosophy as in the second aggregation, and using the weights assigned to the 5 dimensions, in this third aggregation three global composite indicators are obtained for each country. Let us denote by μ_d, ($d = 1, \ldots,5$) the weights assigned to each dimension (see 3.3.1 and Fig. 1). Let us describe the global composite indicators:

- Weak-Weak-Weak composite indicator of country *j*, WWW_j, which provides a measure of the overall performance of country *j*, taking into account all the indicators, sub-dimensions and dimensions, with their corresponding weights, using a fully compensatory scheme:

$$WWW_j = \sum_{d=1}^{5} \mu_d^w WW_j^d,$$

where:

$$\mu_d^w = \frac{\mu_d}{\sum_{l=1}^{5} \mu_l}$$

- Strong-Weak-Weak composite indicator of country *j*, SWW_j, which indicates the worst dimension of country *j*, taking into account the weights of the dimensions.

$$SWW_j = \left\{ \widehat{WW}_j^d \right\}$$

where:

$$\widehat{WW}_j^d = \alpha^t + \left(WW_j^d - \alpha^t \right) \mu_d^s, \; if \; WW_j^d \in \left[\alpha^{t-1}, \alpha^t\right], (t = 0, 1, 2, 3),$$

$$\mu_d^s = \frac{\mu_d}{\{\mu_l\}}$$

- Strong-Strong-Strong composite indicator of country *j*, SSS_j, which, again, drags the worst indicator of country *j*. This indicator is constructed the same as SWW_j, but considering SS_j^d instead of WW_j^d.

As will be seen in the next section, the joint consideration of the composite indicators obtained in the successive aggregations and of the achievement functions of the individual indicators provides decision makers with a complete dashboard. This allows them to not only obtain global performance measures of the countries, but also to detect possible lines of improvement, in order to help in decision-making processes.

4. Results

The WSI-MR was applied to measure the water sustainability of 27 European countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Ireland, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden and the United Kingdom. The data analyzed correspond to 19 indicators covering data from 2000 to 2020 and the results are described in the following subsections.

This section provides the results of the weighting suggested by the experts for each indicator, the results at the indicator level, at the sub-dimension level, at the dimension level and the global results. The results for two countries, Finland and Bulgaria, are also described in detail. The results for these two countries are particularly interesting in highlighting the index's ability to identify red flags in specific indicators and sub-dimensions, which would be masked if a global analysis and/or a total compensation approach had been used directly in the aggregation process.

4.1. Weighting of dimensions and sub-dimensions by experts

The weightings were calculated using the questionnaires described in section 3.3.1. In total 20 questionnaires were collected from academic, scientific and technical water sustainability experts. The questionnaires were distributed online in June and July 2021. The results showed that although the weights were fairly evenly distributed among the five dimensions analyzed, dimensions 1 (Availability) and 2 (Access) obtained a higher relative importance. In line with this result, the sub-dimensions related to the access to and availability of drinking water, and the availability of groundwater were rated the highest.

The final group weights obtained with this procedure can be seen in Fig. 1.

4.2. Indicators and reference levels

More than 50% of Finland, Sweden and Denmark's indicators scored at a high level. Finland and Sweden had the lowest number of low level scores for the indicators related to climate change and water cost; Finland had the lowest scores for productivity, and Sweden the lowest score for protection of aquatic ecosystems and water cost. Denmark scored at the lowest level on the indicators for water availability, watercourse status, groundwater abstraction and water cost. The countries where more than 50% of their indicators had low scores were Cyprus, Romania, Croatia and Italy. All of these countries except Croatia scored worse on the indicators associated with water availability and status. The rest of the countries mostly scored in the middle range. The results of the normalised scores, after treatment of outliers and construction of the achievement functions, associated with each indicator are described in Supplementary material.

4.3. Results by level of aggregation

4.3.1. Results by sub-dimensions

At the first level of aggregation, results were obtained with two approaches: Weak (W) and Strong (S), as described in section 3.3.3. The W approach assumes full compensation between the analyzed indicators and approach S prohibits compensation between them. When compensation between indicators (S) was prohibited, the results showed two particularly problematic sub-dimensions: 1.2. (State) and 3.1. (Climate change). Regarding sub-dimension 1.2., only Slovenia, Romania and Slovakia maintained scores at the high level when a non-compensatory (S) approach was used. This means that their worst scores remained at the first reference level, indicating that the state of their aquatic ecosystems is better in relative terms than for the other countries analyzed. Finland, Lithuania, Croatia and Estonia managed to rank at the best reference level when compensation between indicators (W) was allowed, but failed to maintain this position when compensation was prohibited, meaning that they perform worse on at least one indicator.

Regarding sub-dimension 3.1., France, Spain and Sweden were the only countries that maintained their climate change positions at the high level. In fact, this sub-dimension was the only one that France managed to maintain at the first reference level when compensation between indicators was not permitted. Portugal was the only country that did not manage to keep any indicators at the high level following the (S) approach, with almost half (46.15%) of its sub-dimensions remaining at the low level. Italy, Cyprus, Hungary, Poland were the countries that managed to keep the fewest sub-dimensions in high positions according to the (S) approach. These were, in the case of Italy, 3.3. (Groundwater available), for Cyprus 2.1. (Drinking water) and for Poland 5.1. (Cost of water). Hungary was the only country that did not manage to keep any sub-dimension at the high level. It was precisely in Hungary that the most relevant change was observed when a full compensation approach was employed, which significantly improved its position, particularly in the sub-dimensions 1.1. (Capacity), 3.1. (Climate change), 3.2. (Erosion/Watershed state) and 5.1. (Cost of water), which were at the high level. This is explained by the good performance of some indicators included in these sub-dimensions, such as Water exploitation index in sub-dimension 1.1, Greenhouse gas emissions in 3.1 and Share of landcover types affected by severe erosion in 3.2, which made it possible to compensate for the poor performance of the other indicators. When compensation was prohibited, these good results disappeared, and the weaknesses of each sub-dimension were revealed. Tables 3 and 4 describe the results by country and sub-dimension according to the W and S approaches, respectively.

4.3.2. Results by dimensions

At the second level of aggregation, results were obtained for the indicators with three approaches: Weak-Weak (WW), Strong-Weak (SW) and Strong-Strong (SS) as described in section 3.3.4. The WW approach allowed full compensation at all levels of aggregation, SW allowed full compensation in the first aggregation (indicators), but prohibited it in the second (sub-dimensions), thus detecting the worst sub-dimension, and SS prohibited compensation in all aggregations, thus obtaining the value of the worst indicator. The results for each dimension are described below.

Dimension 1. Availability: Slovenia and Slovakia obtained the best and most robust results, as they remained at the high level until the SS analysis in the two sub-dimensions (1.1.Capacity and 1.2.State) included in the dimension. Finland and Croatia remained at the high level in the SW analysis. Latvia, Lithuania and Sweden ranked high in the WW analysis but worsened their positions in the SW analysis. In the case of Lithuania and Sweden they remained at the medium level when a WW approach was used. However, Latvia fell to the low level when compensation between indicators was prohibited. This is due to the poor performance (low level) of indicator 1.2.1. Related to the ecological health of Latvia's surface waterbodies. The worst scores were for Belgium, Czechia, Cyprus, Germany, Italy, Poland and Spain. These countries ranked at the worst level even in the WW analysis. This means that their overall position was poor, even when compensation between indicators was allowed. These results reflect the need for urgent action in these seven countries, whose short-term sustainability could be seriously compromised.

Dimension 2. Access: The United Kingdom, the Netherlands, Germany, Luxembourg and Greece were at the high level in all three analyses. At the extreme end of the scale were Romania, Croatia, Hungary, Lithuania, Italy and Slovenia, which ranked low in the WW analysis. Looking at the indicator scores and the analysis by sub-dimensions, it can be seen that all these countries were at the low level in all indicators and sub-dimensions, except Hungary, whose poor performance was driven by the poor performance of sub-dimension 2.1 (Drinking water).

Dimension 3. Resilience: Ireland, Latvia, the United Kingdom, Sweden, Czechia, Lithuania, and Hungary scored at the high level in the WW analysis, but no country scored at the high level in the SW analysis in this dimension and all scored at the low level when the SS analysis was performed. This means that all countries had some very poor indicators, which, when compensation was not allowed, pulled down each country's score.

The analysis by sub-dimensions showed that some countries such as Ireland, Latvia, Czechia, Lithuania, Hungary and the United Kingdom ranked high in the sub-dimensions 3.2. (Erosion), 3.3. (Groundwater available), 3.4. (Protection of freshwater ecosystems) from an SS-

Table 3
Scores by sub-dimensions and countries with a weak approach. High level scores in green (above the 66th percentile), medium level scores in yellow (between the 33rd and 66th percentiles) and low level scores in red (below the 33rd percentile).

	Weak (W)												
	1.1	1.2	2.1	2.2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	5.1	5.2
Austria	60,959	59,515	64,858	91,405	62,141	38,672	0,000	31,060	67,162	66,863	69,826	32,411	0,000
Belgium	30,551	13,383	85,204	48,682	50,660	73,643	64,600	65,470	80,627	71,005	51,007	10,313	58,027
Bulgaria	69,054	32,293	49,046	18,186	19,814	39,080	37,856	67,014	0,000	0,000	11,473	89,448	0,000
Croatia	96,658	73,949	19,719	0,000	42,842	29,473	30,445	29,058	46,220	13,757	25,809	49,884	50,813
Cyprus	0,000	50,386	81,426	0,000	16,491	31,411	19,822	0,000	38,899	39,343	42,348	53,721	62,988
Czechia	18,900	24,342	55,634	51,614	48,602	52,107	94,718	69,970	93,510	25,896	35,216	36,070	66,840
Denmark	36,632	30,563	45,532	75,574	75,195	96,832	29,401	68,276	69,100	100,000	83,000	5,304	81,616
Estonia	56,308	61,270	30,461	65,023	20,304	97,255	17,904	76,104	31,675	59,143	27,117	90,621	2,829
Finland	88,058	74,897	81,111	59,003	60,385	93,197	75,294	34,130	84,986	96,376	100,000	25,045	24,101
France	38,904	42,340	54,492	50,989	82,660	51,910	35,283	31,669	52,133	59,657	63,576	33,384	56,535
Germany	26,824	11,737	94,019	88,685	53,140	59,984	47,831	46,768	51,358	79,807	87,816	11,786	66,881
Greece	27,363	62,994	99,056	77,451	35,947	25,359	0,000	58,705	24,102	4,046	66,272	97,655	12,756
Hungary	71,356	42,727	0,000	41,724	68,940	78,155	65,302	54,337	65,578	16,725	19,384	66,000	18,882
Ireland	62,036	68,185	47,289	22,295	47,971	86,419	78,887	100,000	49,035	65,571	65,322	0,000	76,989
Italy	30,480	36,015	27,867	20,142	56,891	0,000	68,438	54,050	30,364	10,520	54,111	63,698	31,815
Latvia	92,122	60,266	30,761	62,052	56,542	94,908	60,612	95,204	11,141	28,864	35,726	89,448	67,971
Lithuania	60,754	74,060	8,710	32,927	31,948	93,358	67,880	84,448	8,374	34,971	14,660	81,241	60,535
Luxembourg	43,456	44,092	96,537	87,651	19,652	44,366	84,527	0,000	53,752	82,914	88,023	0,000	100,000
Netherlands	46,018	22,659	99,056	99,130	42,297	54,991	63,728	98,892	78,399	86,020	100,000	45,279	55,232
Poland	23,901	23,277	51,330	33,065	27,069	52,575	52,180	65,805	48,543	39,343	31,529	69,517	33,322
Portugal	31,427	56,683	32,956	60,899	62,080	31,552	4,677	23,376	22,864	44,743	37,352	59,093	33,774
Romania	36,677	81,317	0,000	0,000	48,481	14,651	100,000	19,774	16,165	7,553	2,674	100,000	16,991
Slovakia	83,637	83,766	74,185	26,884	53,840	65,443	58,028	56,806	98,547	16,185	23,570	66,000	69,257
Slovenia	81,821	74,661	30,761	20,153	42,086	15,452	32,386	74,349	100,000	38,314	49,175	77,724	36,391
Spain	20,827	38,834	62,750	68,720	67,042	26,271	25,626	6,649	20,680	38,057	66,585	42,209	27,877
Sweden	83,771	63,796	33,059	86,400	95,540	71,147	93,287	16,762	74,137	94,305	90,192	12,670	71,561
United Kingdom	45,814	44,150	100,000	100,000	52,555	63,568	98,211	60,986	33,641	77,218	97,177	18,563	79,451

Table 4
Scores by sub-dimensions and countries with a strong focus. High level scores in green (above the 66th percentile), medium level scores in yellow, (between the 33rd and 66th percentiles) and low level scores in red (below the 33rd percentile).

	Strong (S)												
	1.1	1.2	2.1	2.2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	5.1	5.2
Austria	56,043	57,316	64,858	91,405	46,079	13,186	0,000	31,060	67,162	66,863	62,235	32,411	0,000
Belgium	27,404	0,000	85,204	48,682	31,221	64,163	64,600	65,470	80,627	71,005	41,312	10,313	58,027
Bulgaria	66,908	9,006	49,046	18,186	0,000	35,569	37,856	67,014	0,000	0,000	0,000	89,448	0,000
Croatia	93,317	48,632	19,719	0,000	0,471	28,953	30,445	29,058	46,220	13,757	25,157	49,884	50,813
Cyprus	0,000	25,058	81,426	0,000	0,000	30,402	19,822	0,000	38,899	39,343	23,576	53,721	62,988
Czechia	13,885	18,454	55,634	51,614	23,338	46,013	94,718	69,970	93,510	25,896	33,714	36,070	66,840
Denmark	9,414	27,805	45,532	75,574	43,405	93,664	29,401	68,276	69,100	100,000	66,000	5,304	81,616
Estonia	27,777	43,588	30,461	65,023	7,383	94,585	17,904	76,104	31,675	59,143	11,103	90,621	2,829
Finland	84,590	49,794	81,111	59,003	28,857	89,101	75,294	34,130	84,986	96,376	100,000	25,045	24,101
France	33,862	32,574	54,492	50,989	72,313	50,963	35,283	31,669	52,133	59,657	62,825	33,384	56,535
Germany	20,854	7,024	94,019	88,685	29,643	59,758	47,831	46,768	51,358	79,807	86,923	11,786	66,881
Greece	7,921	40,560	99,056	77,451	9,264	25,227	0,000	58,705	24,102	4,046	56,082	97,655	12,756
Hungary	65,292	20,532	0,000	41,724	26,301	56,458	65,302	54,337	65,578	16,725	11,658	66,000	18,882
Ireland	57,266	55,579	47,289	22,295	20,424	84,647	78,887	100,000	49,035	65,571	64,644	0,000	76,989
Italy	27,144	25,134	27,867	20,142	49,583	0,000	68,438	54,050	30,364	10,520	31,760	63,698	31,815
Latvia	84,245	20,532	30,761	62,052	5,731	90,063	60,612	95,204	11,141	28,864	5,736	89,448	67,971
Lithuania	56,725	66,000	8,710	32,927	0,000	87,355	67,880	84,448	8,374	34,971	4,441	81,241	60,535
Luxembourg	35,028	1,829	96,537	87,651	0,000	33,919	84,527	0,000	53,752	82,914	81,692	0,000	100,000
Netherlands	41,837	0,000	99,056	99,130	25,047	9,982	63,728	98,892	78,399	86,020	100,000	45,279	55,232
Poland	16,147	15,632	51,330	33,065	10,128	36,750	52,180	65,805	48,543	39,343	29,237	69,517	33,322
Portugal	27,026	47,366	32,956	60,899	33,190	26,991	4,677	23,376	22,864	44,743	28,226	59,093	33,774
Romania	20,200	73,966	0,000	0,000	2,198	0,000	100,000	19,774	16,165	7,553	0,000	100,000	16,991
Slovakia	74,087	74,095	74,185	26,884	33,138	31,033	58,028	56,806	98,547	16,185	17,717	66,000	69,257
Slovenia	75,646	71,988	30,761	20,153	35,471	0,000	32,386	74,349	100,000	38,314	34,348	77,724	36,391
Spain	19,153	5,192	62,750	68,720	66,473	26,188	25,626	6,649	20,680	38,057	65,163	42,209	27,877
Sweden	82,059	39,947	33,059	86,400	89,955	62,169	93,287	16,762	74,137	94,305	80,385	12,670	71,561
United Kingdom	18,945	34,737	100,000	100,000	29,065	61,868	98,211	60,986	33,641	77,218	94,354	18,563	79,451

approach, however they were at the lowest level with sub-dimension 3.1. (Climate Change). These very poor results in this sub-dimension worsened the results of the Resilience dimension for all countries, except for France, Spain and Sweden, which managed to stay at the high level in their climate change results. In the case of Sweden, the sub-dimension that worsened its performance in dimension 3 was the one associated with the protection of aquatic ecosystems.

Dimension 4. Good Governance: Denmark, Finland, the Netherlands and Sweden managed to stay in the high level when a non-compensatory scheme was used at both levels of aggregation (SS). This means that all indicators associated with this dimension were good and although no compensation was allowed between them, it was not necessary to maintain the position of each of these countries at the high level. On the other hand, Bulgaria, Croatia, Latvia, Lithuania, Hungary and Romania were not able to compensate for their poor performance in any aggregation process and were placed at the low level even when a WW approach was used. Germany, Luxembourg, Austria and the United Kingdom achieved intermediate positions by ranking high when compensation was allowed and moving to a medium level when a strong scheme was used at the second level of aggregation (SW).

Dimension 5. Economic Capacity: The results associated with this dimension were the strongest. The worst positions were obtained by

Table 5
Results by dimensions and countries with a weak-weak, strong-weak and strong-strong approach. High level Scores in green (above the 66th percentile), medium level scores in yellow (between the 33rd and 66th percentile) and low level scores in red (below the 33rd percentile).

	Weak-Weak (WW)					Strong-Weak (SW)					Strong-Strong (SS)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Austria	60,310	78,438	30,876	68,211	16,429	60,705	64,910	0,000	69,826	0,900	56,043	64,910	0,000	62,235	0,900
Belgium	22,834	66,521	63,193	65,031	33,840	16,983	48,682	53,475	51,007	10,313	6,056	48,682	31,547	41,312	10,313
Bulgaria	52,530	33,259	40,854	4,909	45,343	32,422	18,186	22,234	9,584	0,900	13,409	18,186	6,056	0,000	0,900
Croatia	86,451	9,631	32,973	27,630	50,342	78,729	0,000	29,781	19,346	49,884	51,819	0,000	6,440	19,346	49,884
Cyprus	22,648	39,771	16,434	40,510	58,290	0,000	0,000	6,056	42,348	53,721	0,000	0,000	6,056	23,576	53,721
Czechia	21,346	53,578	68,574	48,037	51,242	18,900	51,614	51,795	27,960	36,070	13,885	51,614	25,111	27,960	36,070
Denmark	33,904	60,901	63,976	84,430	42,932	31,010	46,458	29,401	80,612	5,304	9,414	46,458	29,401	66,000	5,304
Estonia	58,539	48,142	48,932	38,065	47,332	56,308	30,576	17,904	27,117	3,652	27,777	30,576	12,084	11,103	3,652
Finland	82,142	69,801	65,036	94,869	24,579	79,504	59,003	39,978	90,580	24,343	52,768	59,003	29,617	90,580	24,343
France	40,448	52,700	49,471	59,314	44,799	38,904	50,989	31,914	57,299	33,384	32,652	50,989	31,914	57,299	33,384
Germany	20,042	91,290	51,337	75,596	38,952	15,639	88,685	47,831	56,813	11,786	11,791	88,685	30,259	56,813	11,786
Greece	43,379	88,004	28,545	36,057	55,792	27,363	77,451	0,000	12,455	13,308	7,921	77,451	0,000	12,455	13,308
Hungary	58,488	21,344	66,086	30,978	42,767	46,998	1,492	56,477	19,384	19,267	22,820	1,492	27,530	11,658	19,267
Ireland	64,800	34,503	77,983	61,025	37,962	62,036	22,295	51,280	55,356	0,000	57,266	22,295	22,731	55,356	0,000
Italy	32,968	23,915	48,193	34,500	47,977	30,480	20,142	11,000	17,049	31,847	26,578	20,142	11,000	17,049	31,847
Latvia	77,803	46,768	75,094	27,042	78,858	61,318	30,862	58,277	19,285	68,845	22,820	30,862	10,735	5,736	68,845
Lithuania	66,735	21,098	68,236	19,139	71,031	60,754	9,808	32,141	14,660	60,684	56,725	9,808	6,056	4,441	60,684
Luxembourg	43,742	91,991	39,443	77,271	49,309	43,456	87,651	6,056	58,315	0,000	7,549	87,651	6,056	58,315	0,000
Netherlands	35,519	99,093	65,361	89,956	50,187	24,557	99,098	46,647	86,447	45,279	6,056	99,098	17,655	86,447	45,279
Poland	23,620	41,986	49,418	38,469	51,670	23,901	33,065	28,158	31,529	34,213	16,147	33,065	14,325	29,237	34,213
Portugal	42,779	47,250	28,938	35,707	46,609	31,427	32,958	4,677	26,640	34,653	27,026	32,958	4,677	26,640	34,653
Romania	56,742	0,000	50,156	7,778	59,069	36,677	0,000	20,767	2,674	17,428	20,200	0,000	7,850	0,000	17,428
Slovakia	83,695	49,988	58,187	41,457	67,606	83,637	26,884	56,071	21,069	66,000	74,087	26,884	31,689	17,717	66,000
Slovenia	78,602	25,334	41,748	59,523	57,343	79,310	20,153	21,301	46,355	37,199	75,646	20,153	11,000	34,348	37,199
Spain	28,921	65,804	31,309	45,599	35,142	20,827	62,897	11,485	25,270	28,017	10,295	62,897	11,485	25,270	28,017
Sweden	74,792	60,346	70,435	87,130	41,708	64,200	34,548	19,742	83,773	12,670	44,728	34,548	19,742	80,385	12,670
United Kingdom	45,066	100,000	70,703	74,059	48,586	45,814	100,000	55,023	45,697	18,563	18,945	100,000	29,787	45,697	18,563

Austria and Finland, while Latvia, Lithuania and Slovakia were in the high level. Latvia and Slovakia's scores were robust, as they were maintained in all compensation schemes.

Table 5 shows the results per dimension and per country for the WW, SW and SS approaches.

4.3.3. WSI-MR global results. The cases of Finland and Bulgaria

The results of the third aggregation were calculated using three approaches: Weak-Weak-Weak-Weak (WWW), Strong-Weak-Weak (SWW) and Strong-Strong-Strong (SSS), as described in section 3.3.5. The results highlighted Finland, the Netherlands, Sweden and the United Kingdom as the countries that showed the best overall position, with values at the high level when a fully compensatory approach was used at all levels of aggregation (WWW). When compensation between dimensions was prohibited (SWW), none of these countries managed to remain at the high level. All the countries except Denmark, Estonia, Ireland, France, Luxembourg, the Netherlands, Slovakia, Sweden and the United Kingdom were at a low level. This implies that all of them obtained at least one low level dimension. When prohibiting compensation between indicators (SSS), all the countries analyzed were at the low level. This means that they obtained at least one indicator at the worst level.

Table 6 shows the results per country according to the WWW, SWW and SSS approaches.

Figs. 2 and 3 show the relative positions of the countries analyzed using the WWW, SWW and SSS approaches, and the rankings of these countries using a weak sustainability approach (Fig. 4) and a strong sustainability approach (Fig. 5). Using the weak sustainability approach, i.e. when the countries were ranked using the WWW approach; the United Kingdom, the Netherlands, Finland and Sweden obtained the best positions. However, Finland moved from a high level with WWW to a low level with SWW (from green to red), although it achieved the best position by far with the SSS approach, among the four best performing WWW countries. This suggests a particularly weak dimension for this country. The countries with the worst WWW positions were Romania, Cyprus, Bulgaria and Italy. This means that they obtained the worst positions in all indicators and dimensions analyzed.

Table 6
WSI-MR index results by country with the weak-weak-weak, strong-weak-weak-weak and strong-strong-strong-strong approaches. High level Scores in green (above the 66th percentile), medium level scores in yellow (between the 33rd and 66th percentile) and low level scores in red (below the 33rd percentile).

	WWW	SWW	SSS
Austria	52,295	19,218	5,554
Belgium	49,916	22,834	6,056
Bulgaria	35,835	9,201	5,042
Croatia	41,853	9,631	0,000
Cyprus	35,225	19,222	0,000
Czechia	47,726	21,346	13,885
Denmark	56,589	33,904	9,414
Estonia	48,550	42,333	8,591
Finland	68,028	25,996	25,800
France	49,174	40,448	32,096
Germany	55,529	20,042	11,791
Greece	51,451	29,295	5,554
Hungary	43,588	21,344	1,492
Ireland	54,857	34,503	5,554
Italy	36,824	23,915	14,702
Latvia	61,083	27,952	9,902
Lithuania	48,747	21,098	8,805
Luxembourg	60,970	43,742	5,554
Netherlands	68,045	35,519	6,056
Poland	40,410	23,620	16,147
Portugal	40,596	29,622	9,443
Romania	34,180	0,000	0,000
Slovakia	60,619	45,207	20,052
Slovenia	52,494	25,334	14,702
Spain	41,818	28,921	10,295
Sweden	67,003	45,796	16,091
United Kingdom	68,067	45,066	18,945

With a strong sustainability approach, i.e. when the countries were ranked according to the SSS analysis (Fig. 5), France, Finland, Slovakia and the United Kingdom obtained the best positions, while Croatia, Cyprus, Romania and Hungary, obtained the worst positions. The countries that managed to rank the best were those that achieved the "worst results". Cyprus and Romania were in the worst positions in the ranking with both weak and strong sustainability approaches, suggesting that they were the worst performers and also did not score well enough in terms of any indicators and dimensions to compensate for these poor results. On the other hand, some countries such as Austria, Finland, Latvia, Croatia and Romania and, to a lesser extent, Germany, lost relative positions when the SWW approach was used. This points to poorer results in full dimensions such as dimension 5 in the case of Finland (24,579) and Austria (16,429), dimensions 2 (0,000) and 4 (7778) for Romania, dimension 2 (9631) for Croatia, dimension 4 (4909) for Bulgaria and dimension 1 (20,042) for Germany.

Fig. 4 shows a scatter plot of the WWW and SWW results. The countries with the weakest results, i.e. those that were below the centre of the graph, were Romania, Bulgaria, Croatia, Cyprus, Italy, Poland, Hungary and Czechia. This means that these countries achieved the worst results in all sub-dimensions and did not achieve sufficiently high scores to compensate for these poor results. Austria, Germany, Belgium and Slovenia achieved better scores when using the WWW approach but failed to rank above the average score when using the SWW approach. This suggests that although the scores for some of their sub-dimensions were poor, they achieved some indicators with sufficiently high scores to compensate for the weaker indicators. The strongest positions went to Sweden and the United Kingdom, which achieved the best scores using both the WWW and SWW approaches.

It is worth noting the results for Finland, which went from achieving a score of 68.028 (high level) when using the WWW approach to a score of 25.996 (low level) when using a SWW approach. This result shows that there is at least one dimension with many of its indicators in the low level, as suggested by the results in Fig. 2. The light plot depicted in Fig. 5 shows the weaknesses or red flags in this country more clearly. In the case of Finland, the indicators associated with dimension 5 Economic Capacity (in red) were responsible for this result. Finland was at the low level for both indicator 5.1.1, which reflects the estimated cost of water in the country, and indicator 5.2.1, the efficiency of water use for production. The best results were obtained in dimension 4. Good Governance, 1. Availability and 2. Access, with almost all scores in green. In the figure we can seen that the causes of the worst performance in dimension 3. Resilience, are the indicators and sub-dimensions associated with climate change (in red) and the protection of aquatic ecosystems (in yellow). Although the Netherlands, Sweden and the United Kingdom also scored low on the indicators associated with the cost of water (5.1.1.), they attained high scores linked to water productivity (5.2.1.). This made it possible to compensate for the poor results for water cost when the SWW approach was used. For this reason, they were at a medium level when compensation between dimensions was prohibited, unlike Finland.

Some countries, such as Bulgaria, Croatia, Slovakia and Romania also deserve special attention. These countries performed well in most of the indicators associated with dimension 1 (Availability), but very poorly in other dimensions, such as 3 (Resilience) and 4 (Good governance). In order to better identify the problem in Bulgaria, a light graph is shown in Fig. 6. It can be seen that in the case of Bulgaria, there is a great disparity between the indicators collected and between some sub-dimensions. In fact, it seems to be the opposite case to Finland, as the best scores (in green) were those related to the protection of aquatic ecosystems and the cost of water, as well as its availability. In contrast,

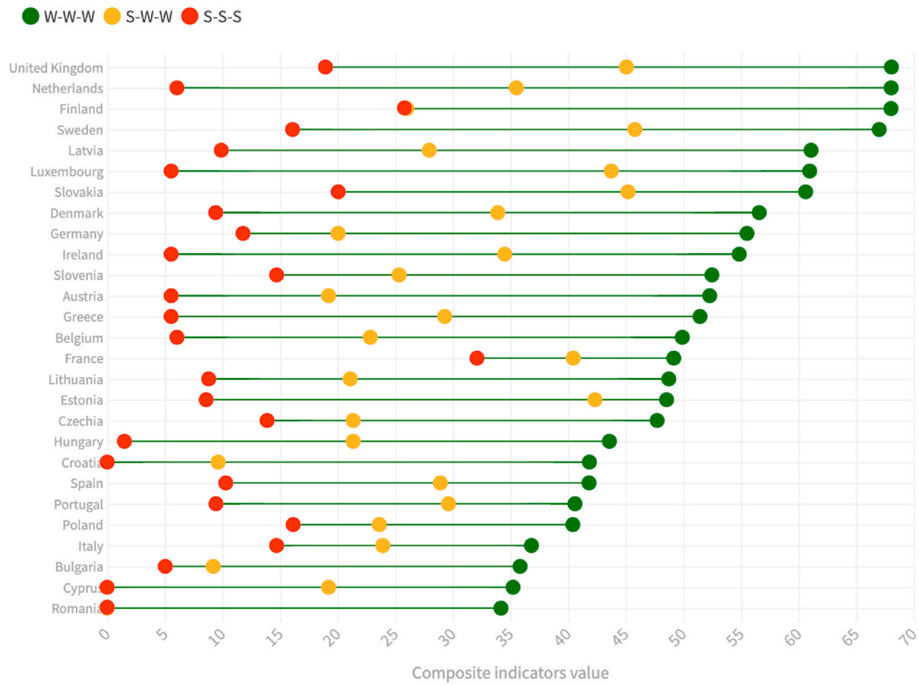

Fig. 2. Composite Indicator Rank and Scores Value green. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

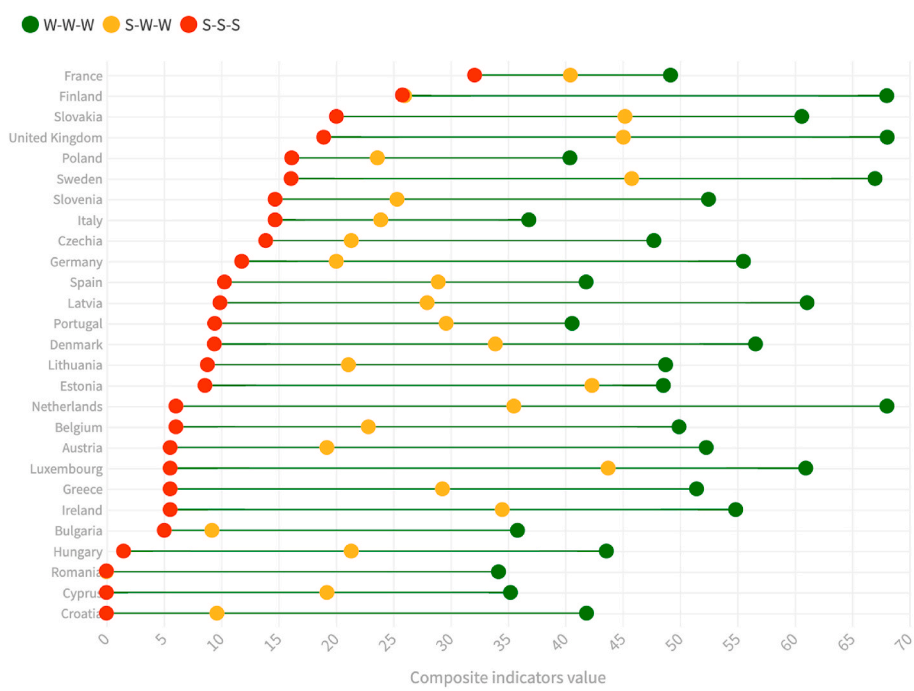

Fig. 3. Composite Indicator Rank and Scores Value red. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

all the indicators associated with good governance had the worst relative scores (in red); while the scores associated with the capacity indicators (1.1.1. and 1.1.2.) were at the high level and the status indicator 1.2.1. at the medium level. Fig. 6 shows that in addition, the water cost indicators obtained the best relative position. While the water productivity indicators obtained the worst relative position. (Level of water stress (%)), 2.2.1. (Population connected to at least secondary wastewater treatment), 3.1.2. (Greenhouse gas emissions intensity by energy (index, 2000 = 100)) and 3.1.3. (Contribution to the international 100bn USD commitment on climate related expending (Euro per inhabitant)). Similar results, although with less marked differences, were obtained for other eastern European countries, such as Croatia, Romania and Slovenia. These countries performed relatively well on indicators related to the quantity and quality of renewable resources, but poorly in terms of governance, resilience and water productivity.

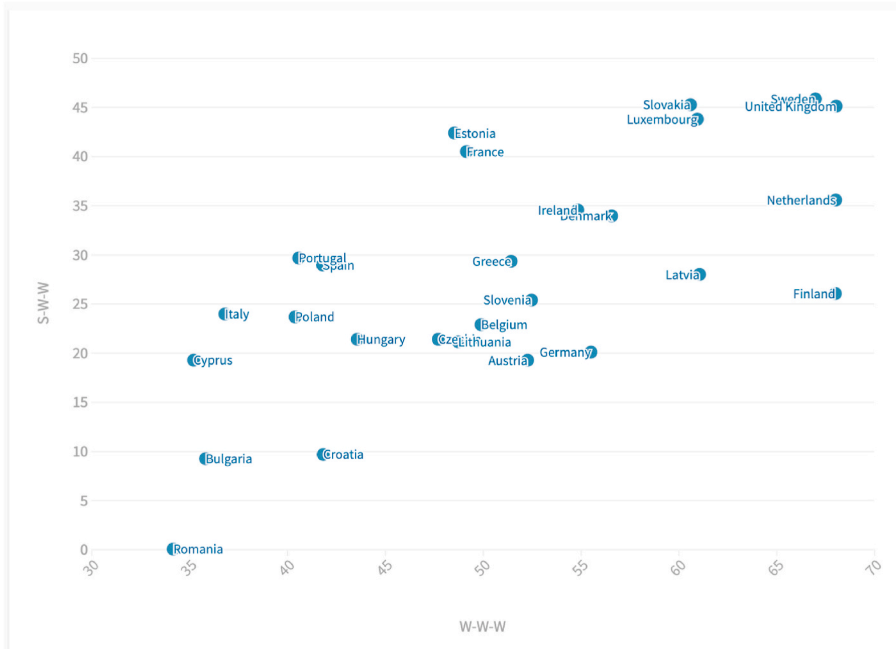

Fig. 4. Scatter plot water.

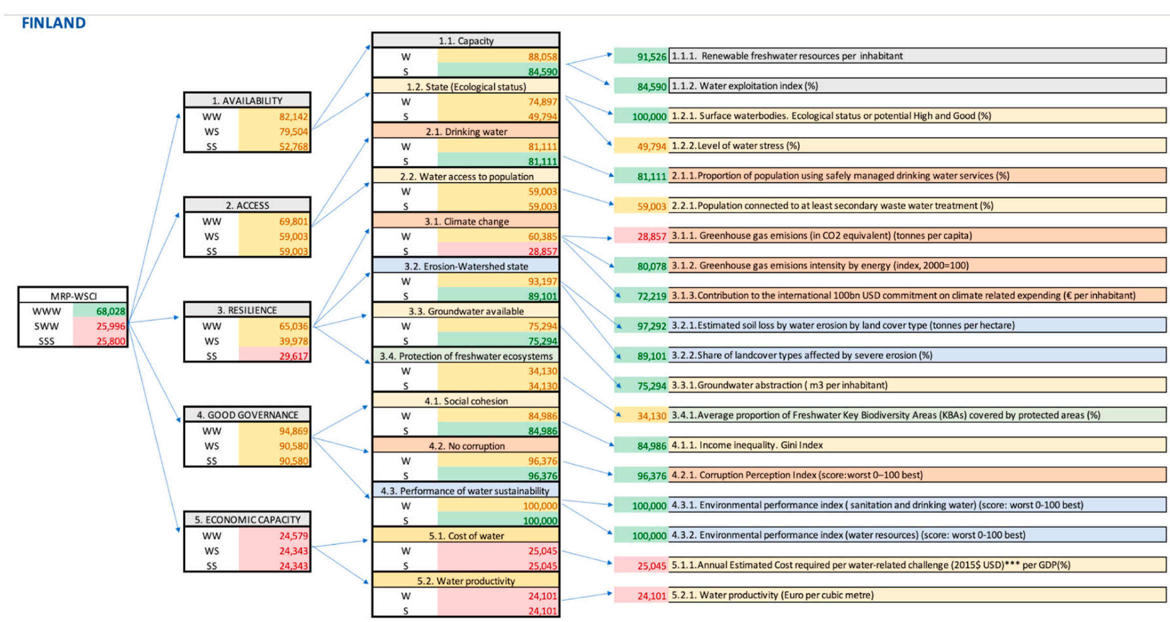

Fig. 5. Light plot of WSI-MR results for Finland.

5. Discussion

The importance of integrated environmental policies for decision-making is particularly evident in the context of water resources [71]. From an operational perspective, the essential issue is that decision-making needs measurement and evaluation, but sustainability cannot be measured directly [72]. Given the multidimensionality of water-related problems, the choice, design of indicators and the aggregation and synthesis processes used are essential for environmental economic analysis, decision-making and policy formulation.

Although different definitions of strong and weak sustainability have been proposed in various works [50], one can broadly assume, in the context of composite indicators, the idea of weak sustainability as a less "demanding" measure of sustainability, in the sense that it allows trade-offs between good and poor performance on the selected indicators. Similarly, a strong sustainability measure can be seen as a more "demanding" measure that does not allow trade-offs between indicators. More specifically, different degrees of trade-off between indicators, sub-dimensions and dimensions of an ecological, economic and social nature can also be combined to define different degrees of sustainability. Some works such as [25,41] have already successfully used the flexible trade-off approach between indicators to measure strong sustainability and weak sustainability in 8 provinces and 18 municipalities in the region of Andalusia (Spain), respectively.

The application of the WSI-MR presented in this paper provided results at each level of aggregation and, depending on the degree of trade-off, the results are presented in terms of weak and strong sustainability, pointing out the weaknesses and strengths of each country and

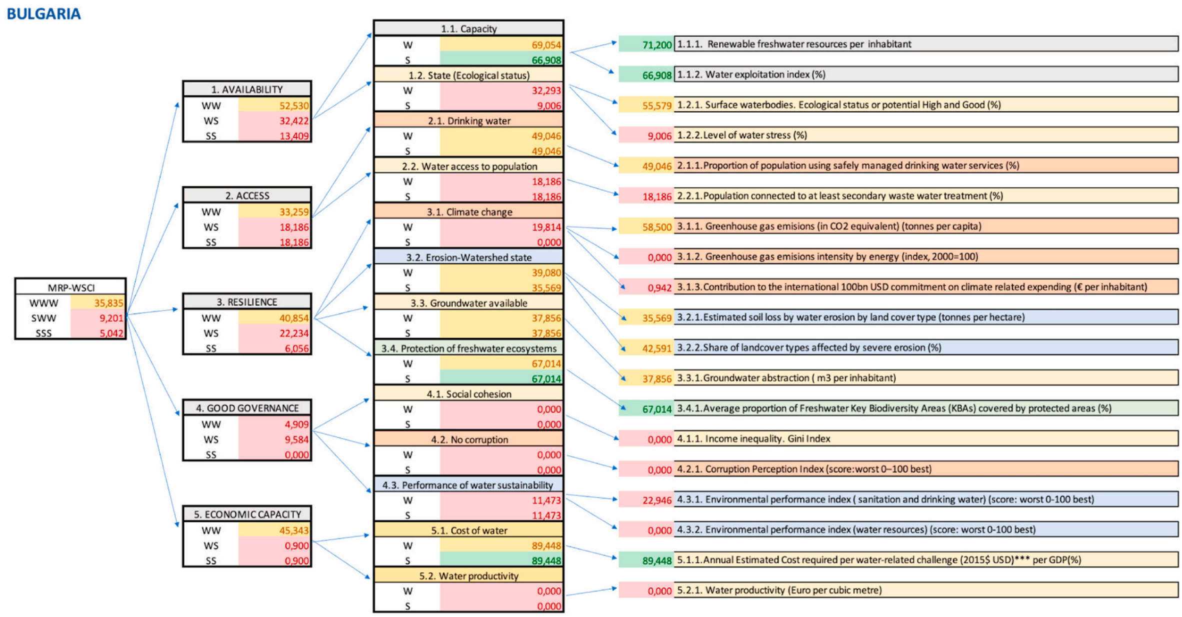

Fig. 6. Light plot of WSI-MR results for Bulgaria.

identifying some vulnerable dimensions. At the first level of aggregation, the analysis from a non-compensatory approach permitted the identification of two particularly vulnerable sub-dimensions; the state of water resources and climate change. Romania, Slovenia and Slovakia were the only countries that maintained their scores at the high level when compensation between indicators was prohibited. Regarding the sub-dimension related to climate change, France, Spain and Sweden were the only countries that maintained their positions at the high level. In fact, this sub-dimension was the only one that France managed to maintain at the best level when compensation between indicators was prohibited. France's policy emphasis on climate change mitigation is remarkable. Between 1990 and 2000, French urban policies focused on two concepts that were sometimes diffusely related; "governance" and "sustainable development" and promoted economic, social and institutional transformations centred on participation and the promotion of deliberative processes. However, since 2000 and especially since the *Grenelle de l'Environnement* in 2007, sustainability policies in France have focused on a measurable, evaluable objective: climate change mitigation. This shift was implemented through strategies such as the Territorial Climate-Energy Plans, which are mandatory for cities with more than 50,000 inhabitants [86]. These policy guidelines were undoubtedly effective and are reflected in the results presented in this paper.

The WS and SS analyses allowed us to detect the poor performance of almost all the countries in relation to resilience at the second level of aggregation. The poor performance of this dimension was mainly caused by the poor results of the sub-dimension associated with climate change, even though it was not the weighted sub-dimension with the highest weight in the aggregation. These results are worrying, as climate change is a significant indicator of water security since it directly and significantly affects terrestrial water storage. Several studies have already analyzed the consistency of this relationship, showing that decreases in terrestrial water storage translate into increases in future droughts [73]. estimated that by the end of the 21st century, both global land area and populations with extreme drought conditions could more than double due to declines in terrestrial water storage, especially in the Southern Hemisphere, the U.S. and south-western Europe. These severe droughts and other consequences of climate change, in addition to the clear direct effects on the availability and status of water resources, intensify human-wildlife conflicts in a much broader sense [74]. The poor performance in the climate change dimension highlights the need to review and strengthen national and international policies aimed at mitigation, particularly in countries such as Bulgaria, Cyprus, Estonia, Lithuania, Luxembourg and Poland.

The overall results obtained at the third and final level of aggregation showed that none of the countries analyzed achieved acceptable scores in terms of strong sustainability. That is, when a non-compensatory approach was used in all aggregations, as all the scores were at the low level. This shows that all countries had at least one indicator at the low level. This result should not be surprising, given the current global water crisis and given the high number of relevant indicators that were used in the WSI-MR. When compensation was allowed at all levels of aggregation, the results provided the best overall positions for the Netherlands, Finland, Sweden and the United Kingdom. However, the WSS analysis at the third level of aggregation revealed particularly strong weaknesses for some countries in some sub-dimensions.

Austria and Finland scored the worst in terms of the cost of water, although Finland performed very well in all other dimensions and Austria in all other dimensions except Resilience. This suggests that although water is more expensive than in the other countries, they have good, available water resources. Moreover, their GDPs are among the highest, so this result should not be a cause for concern. However, it is worth looking at the case of Finland. This country performed poorly in dimension 5, because in addition to its poor performance in relation to the cost of water, it also scored poorly on the indicators associated with water productivity. These results could be explained by a decentralised system of government in a predominantly rural society, which could affect the efficiency of, for example, the supply network. Finland has one of the largest water supply networks, in metres of pipe per inhabitant, of any European country. It has 19.5 m of drinking water network length per capita and 9.2 m of waste water network length per capita [75]. On the other hand, it is important to highlight the leading role of the paper industry in this governance context, with a strong water footprint [76], as it could also contribute to these results. Finland is the third largest paper and paperboard producer in the EU, after Germany, Sweden and Italy, with a contribution of 11% of European production [77] and a global pulp production contribution of 6.5% [76]. Ultimately, low water productivity associated with decentralised governance in a predominantly rural context [78], together with seasonal droughts particularly important in some southern parts of the country [79] and an economy based on a water-intensive industry, require paying attention to Finland, even if it has performed well in all dimensions.

Other countries that deserve specific analysis are some Eastern European countries such as Croatia, Slovakia, Bulgaria, Latvia and Romania. The first two scored well on the quantity and condition of their water resources, Bulgaria and Latvia scored well on quantity but not on condition, and Romania scored well on condition but not on quantity. These countries have another point in common; they scored the worst in the dimension associated with good governance. Although they performed well on the indicators associated with water availability, water status, and water cost, they performed the worst in terms of water governance and water productivity. Considering that they are among the countries analyzed with the lowest GDP and population density rates, these good results could be related to reduced water exploitation due to low economic development and reduced anthropogenic impact. However, given a potential development scenario 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 water resources availability will disappear, making it very difficult to control the impact of demographic and economic expansion on these resources. In fact, at the end of 2020, the Council of Ministers adopted the Bulgarian National Development Programme 2030, which focuses on three main strategic objectives: accelerated economic development, population growth and reduction of inequalities [80]. Both accelerated economic development and population growth could seriously compromise Bulgaria's water capacity if institutional constraints are not addressed. Although Bulgaria's approach to moving towards the SDGs with environmental actions has water management as one of its priorities (SDG 6), it would be desirable to focus efforts on policies aimed at improving the identified institutional constraints. This effort is urgent if one takes into account the war situation in nearby countries, such as Ukraine, which could worsen some indicators related to the economic and political stability of these countries in the short term.

The 2018 edition of the United Nations World Water Development Report stated that nearly 6 billion people will face drinking water scarcity by 2050 [81]. This figure is alarming in itself, but growing demand for water, shrinking water resources and increasing water pollution, driven by dramatic changes in populations and economic growth appear to have worsened this estimate [82]. In Europe, projections made on soil loss due to water erosion [83] and on the effects of climate change on water scarcity in agricultural areas [84] show extremely worrying results for water sustainability in the not too distant future. On the other hand, the issue of water sustainability should not be addressed exclusively from a local or national perspective, or even within EU boundaries. Global trade in agricultural commodities alone generates international virtual water flows amounting to 1250 billion cubic metres per year [85]. The heavy dependence of many countries, such as those in European, on exports of water-intensive commodities such as cotton and soybeans from countries like Brazil highlights the need to address the problem of water sustainability very well from an international perspective.

Some marginal solutions, proposed to contain water scarcity, can certainly alleviate future shortages of clean water. Such would be the case of those currently proposed in the United Nations World Water Development Report [81], aimed at improving the science and technology of water treatment, water management and supply, and raising awareness of water conservation and saving water. However, strong political will is needed to enforce global regulations, especially in countries where production and population are accumulating, as unregulated development is no longer sustainable.

6. Conclusions

The construction of composite indicators to measure water sustainability is particularly appropriate given the multidimensionality of water resources. In this sense, the WSI-MR contributes to improving the measurement of countries' sustainability in terms of water, using different trade-off approaches sequentially at different levels of aggregation. In particular, the proposed indicator has permitted: 1) providing a measure of strong and weak sustainability at different levels of aggregation, 2) identifying early warning signals and 3) identifying vulnerable dimensions. The application of the WSI-MR identified the Netherlands, Finland, Sweden and the United Kingdom as the most sustainable countries in terms of water from a weak sustainability approach. In contrast, none of the 27 countries analyzed were found to be sustainable in terms of strong sustainability. Belgium, Cyprus, Czechia, Germany, Italy, Poland and Spain scored the worst in terms of the availability of water resources in good conditions, even in terms of weak sustainability. These results suggest the need for urgent action in these countries as their water resources are the most compromised in the short term. The resilience dimension was found to be particularly vulnerable, mainly due to the poor performance of climate change-related indicators in all countries except France, Spain and Sweden.

Warning signs have been identified for some Eastern European countries such as Bulgaria, Croatia, Latvia and Slovakia with good current availability of water resources, but with reduced water productivity and strong governance constraints. These countries could see the sustainability of their water resources compromised in a scenario of economic and demographic growth, if these constraints are not addressed. This may be particularly challenging in the short term due to the current war in Ukraine, which may increase political and economic instability in these countries. Weaknesses have also been identified in some countries with good overall performance, such as productivity and the cost of water in Finland. Policy strategies on water security should focus on addressing these weaknesses to avoid potential problems in the future.

The proposed indicator has important advantages for the assessment, planning and monitoring of international water policies, in terms of measuring water sustainability by simultaneously considering participation, sequential aggregation and flexible compensatory scheme between indicators.

The participatory component has made it possible to simultaneously consider the knowledge of different experts from the academic, scientific and technical fields. The practical implications are even more interesting, taking into account the application of the index in the evaluation of international water sustainability policies. For example, the WSI-MR allows the integration of the assessments of different stakeholders and/or evaluators from different countries and regions. This can be very useful to prevent conflicts and also allows enriching the decision-making process by including the know-how of different experts.

Flexible compensation is also extremely interesting for the assessment of sustainability policies. The wide range of sustainability gradations that the proposed index allows to calculate, from the weakest to the strongest sustainability, is very useful to identify different country rankings according to the objectives defined in international sustainability strategies. In this way, the WSI-MR could be used as a very useful tool to perform a sensitivity analysis according to the potential levels of demand in terms of sustainability of the different institutions.

On the other hand, sequential aggregation provides the possibility to analyze changes at the dimension and sub-dimension level and to identify warning signals in advance. This anticipatory nature is particularly necessary in the current context of the world water crisis and could avoid situations of water scarcity of no return for the analyzed countries.

The application of the proposed index has provided a current diagnosis of the situation in the countries analyzed that considers weak and strong sustainability from different approaches in an integrated manner. It also allows the integration of the know-how of expert panels and/or stakeholder groups in the analysis. On the other hand, it permits the identification of early warning signals on specific indicators, which is very interesting for planning and designing future strategies and for redesigning current policies in order to achieve the desired objectives.

The main limitations of this work are associated with the availability of current, homogeneous data. Although the EU has a homogeneous and relatively complete database, further efforts are needed to update these databases. This will also make it possible to carry out the study with a certain periodicity and to monitor the progress of the different countries. On the other hand, there is an urgent need to promote and support the creation of databases on water resources in resource-poor countries that are strong exporters of virtual water to countries with higher income levels.

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.

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Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.seps.2022.101433.

Appendix 1. Meta-Goal Programming procedure for cardinal preference aggregation

The preference aggregation procedure followed in Section 3.3.1 is fully described in Ref. [68]. Anyway, for the sake of completeness, we describe its main features in this appendix. Let us assume that J experts ($j = 1, \ldots, J$) assess cardinal weights to I indicators ($i = 1, \ldots, I$). Let us denote by ω_{ij} the weights assessed by expert j to indicator i. We denote by Ω the set of all possible weights. The aim is to find a group weight $\underline{\omega}_i \in \Omega$, for each indicator i, based on the individual assessments given. Following the classical Goal Programming notation, the following goals can be built:

$$\underline{\omega}_i + n_{ij} - p_{ij} = \omega_{ij} \ (i = 1, \ldots, I, j = 1, \ldots, J),$$

where $n_{ij} \geq 0$ and $p_{ij} \geq 0$, are, respectively, the so-called negative deviation variables (measuring under-achievements) and positive deviation variables (measuring over-achievements). Given this formulation, four achievement functions can be formulated:

- *MD*: The maximum deviation from each expert weight ω_{ij} to the corresponding group weight $\underline{\omega}_i$:

$$MD = \left\{ n_{ij} + p_{ij} \right\}$$

- *MADE*: The maximum aggregate deviation per expert:

$$MADE = \left\{ \sum_{i \in I} \left(n_{ij} + p_{ij} \right) \right\}$$

- *MADI*: The maximum aggregate deviation per indicator:

$$MADI = \max_{i \in I} \left\{ \sum_{j \in J} \left(n_{ij} + p_{ij} \right) \right\}$$

- *TAD*: The total aggregate deviation:

$$TAD = \sum_{i \in I, j \in J} \left(n_{ij} + p_{ij} \right)$$

Now, let $\widehat{MD}, \widehat{MADE}, \widehat{MADI}, \widehat{TAD}$ be aspiration (desired) values for each of the achievement functions. In our case, these will be the values that these functions achieved for the group weights defined by the geometric mean of the individual weights. Then, the final group weights are the optimal solutions of the following (meta-goal programming) optimization problem:

$$\left\{ max \frac{n_{MD}}{\widehat{MD}} + \frac{n_{MADE}}{\widehat{MADE}} + \frac{n_{MADI}}{\widehat{MADI}} + \frac{n_{TAD}}{\widehat{TAD}} s.t. \underline{\omega}_i + n_{ij} - p_{ij} = \omega_{ij} (i=1,\ldots,I; j=1,\ldots,J) \underline{\omega}_i \in \Omega (i=1,\ldots,I) n_{ij} + p_{ij} \leq MD (i=1,\ldots,I; j=1,\ldots,J) \right.$$

$$\sum_{i \in I} (n_{ij} + p_{ij}) \leq MADI (j=1,\ldots,J) \sum_{j \in J} (n_{ij} + p_{ij}) \leq MADE (i=1,\ldots,I) \ TAD = \sum_{i \in I, j \in J} (n_{ij} + p_{ij}) \ MD + n_{MD} - p_{MD} = \widehat{MD} \ MADE + n_{MADE} - p_{MADE} = \widehat{MADE} \ MADI$$

$$+ n_{MADI} - p_{MADI} = \widehat{MADI} \ TAD + n_{TAD} - p_{TAD} = \widehat{TAD} \ \frac{p_{MD}}{\widehat{MD}} + \frac{p_{MADE}}{\widehat{MADE}} + \frac{p_{MADI}}{\widehat{MADI}} + \frac{p_{TAD}}{\widehat{TAD}} = 0 \ n_{ij}, p_{ij} \geq 0 (i=1,\ldots,I; j=1,\ldots,J) \ n_{MD}, p_{MD}, n_{MADE}, p_{MADE}, n_{MADI}, p_{MADI}, n_{TAD}, p_{TAD} \geq 0$$

The optimal values obtained are expected to improve the aspiration levels set.

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