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Assessing water urban systems to the compliance of SDGs through sustainability indicators. Implementation in the valencian community

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ABSTRACT

The sustainability improving must be supported in the achievement of the sustainable development goals (SDGs). The research shows a procedure, establishing 136 indicators, which are linked to the management of water systems. The procedure classified each indicator according to its intervention in the water cycle, measuring the level of sustainability applied to water systems. This methodology assesses the water systems possible and establishes a benchmarking on sustainable aspects. The developed database and the proposed procedure enable the establishment of an evaluation of the SDGs in any water system, establishing different four levels of sustainability benchmarking. These indicators were applied to 110 worldwide case studies, which were obtained from the background developed in the research. Applying this methodology will allow companies and water system managers to assess the SDG targets and incorporate new challenges to improve sustainability. As example, the methodology was applied to six real supply systems, which are located in Spain. According to the results, the contribution to water supply compliance is 42% of sustainability targets.

1. Introduction

The search for sustainable development in the cities is crucial since they are the biggest human habitat and the element that consumed the most resources (Kissinger & Stossel, 2021). In addition, cities are the core of social, economic, technological, and environmental development that is progressing rapidly (Marquez-Ballesteros et al., 2019). City management has become a challenge for the government and society. The development of the urban area established an increase in the demand for resources. It increases the pressure on the different resources (Wątróbski et al., 2022). To avoid putting at risk the different resources as well as guarantee sustainability in the urban areas imply water managers must promote actions that lead to sustainable cities (Zaman et al., 2021).

Water and energy are the most used resources in the development of resilient cities (Nezami et al., 2022). The actual population and its development will increase in the following years. It will imply the water demand consumed by cities will rise as well by more than 50% by 2050 (Zaman et al., 2021). This will put at risk the capacity of the resources, and therefore sustainable actions and management must be considered (Nezami et al., 2022). This challenge causes urban water sustainability must be implemented and evaluated. The difficulty is located because sustainability is complicated to measure effectively the actions taken to improve sustainability (Liu et al., 2022). One of the possibilities to measure this sustainability is the use of the different sustainable development goals (SDGs) defined by the Union Nations. Recently, different researchers attempted to assess the contribution of implemented action in the achievement of the SDGs, such as indicators and other measures (Kissinger & Stossel, 2021). It is necessary to establish objectives, actions, and measurements to achieve all the SDGs and obtain sustainable cities to guarantee green management of these urban areas (Marquez-Ballesteros et al., 2019).

Water resources are essential for social and economic, and the growth of societies is limited by their access and availability (Garcia et al., 2021). The evaluation and design of sustainable water resources should consider the economic, environmental, and social aspects that the concept encompasses when taking solutions (Leigh & Lee, 2019; D. D. Li et al., 2022). Stakeholders emphasize the development of new technologies, and methodologies to improve sustainable actions in UWS, climate change mitigation as well as developing green communities

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Table 1
Common issues of UWS according to the sustainable dimension. Benavides Muñoz & Cabrera, 2010; Leigh & Lee, 2019; World Water Assessment Programme (United Nations) et al., 2021.

SUSTAINABLE DIMENSION	ISSUE
Social	• Lack of training for the community with • Water saving strategies. • Network coverage
Economical	• Poor rate policy (recovery cost) • High energy requirements, therefore higher operation cost
Technical (Asset)	• Low efficiency of the network (high pressure, pipe leaking, ao) • Lack of renovation or maintenance to infrastructure with a useful life longer than the design • Lack of measurement and control instruments • Low energy efficiency • Poor water quality due to fatigued infrastructures
Environmental	• High extraction of the resource • Affectations in the basins due to the high demands (ecological flow-conservation of hydric resources) • Gas emissions

(Spiller, 2016a).

New methodologies and technologies are being used to assess sustainability in UWS (Blackmore & Plant, 2007; El-Sayed et al., 2010). The ones that are being mostly used among water managers are the smart grid systems and Digital Twins, which integrate information and communications technologies to improve sustainable cities (X. X. Li et al., 2022). The use of these technologies improves the knowledge of values related to flow, pressure, frequency, and users, among others, enabling the enumeration of the different variables to define indicators (Public Utilities Board Singapore, 2016). The use of these indicators enables the evaluation of the different targets of the SDGs and therefore, the contribution to developing sustainable city communities (Byeon et al., 2015). The different water companies have to achieve sustainable development; therefore, they should be able to measure their contribution to the accomplishment of the SDGs (Rey & Sachs, 2012). Water managers must consider actions to assess its sustainability, such as the implementation of indicators (Hannah Smith et al., 2022).

1.1. *Influence of the SDGs on the sustainability of the water systems*

Urban water systems (UWS) can be classified into four groups: drinking water, wastewater, stormwater, and water treatment systems (Chhipi-Shrestha et al., 2017). To provide services, UWS expends resources such as energy and other materials and releases some waste like greenhouse gasses, effluents that can contain heavy metals, a.i. (Chhipi-Shrestha et al., 2017). Therefore, UWS should be able to provide security and sustainable services for the community (Dong et al., 2017). Among many of its characteristics, an urban water system implies that it should be sustainable: "designed and managed to contribute to the objectives of society, while preserving its ecological, environmental, and hydrological integrity" (Loucks et al., 1999). Considering that solutions taken should contemplate a multidimensional view that encompasses the entire concept of sustainability (D. D. Li et al., 2022).

Sustainability in water systems nowadays should be overlooked through the 3 dimensions of sustainability (Behzadian & Kapelan, 2015; Lai et al., 2008). This should consider (Cunha Marques et al., 2015): (i) Social dimension: access to water services, meeting users' needs, and supporting the community; (ii) Environmental dimension: impact of UWS on the natural systems, reduction of emissions and waste, and efficiency of water, materials, and energy; (iii) Economic dimension: affordable fare policies that allow cost recovery; (iv) Asset dimension: performance, durability, and adaptability of the system and it is infrastructure.

The implementation of sustainable actions in water systems still faces many challenges nowadays, mostly because of the measuring, and analysis of data provided by new technologies (Richter et al., 2018). Also, the system scale, the meteorological conditions, and the system's environmental limits complicate the sustainability assessment (Dong et al., 2017). Another regulatory variable of sustainability in UWS is the system's policy framework (Bolognesi, 2014). There are many causes of unsustainability in the actual UWS such as the lack of policies and values around the different uses of water (Lundin & Morrison, 2002). The unsustainable supply-demand balance (Bolognesi, 2014), and poor fare policies (no cost recovery), are very common (Milman & Short, 2008). Due to the industrial pollution of effluents, some reservoir has been closed due to poor water quality which decreases the availability of resources in some areas leading to water stress (Yang et al., 2016). Table 1 shows some usual problems according to the sustainable dimensions.

Sustainable development seeks to satisfy present needs without compromising the capacity of the resources in the long-short term based on economic, environmental, and social aspects (Gro Harlem Bruntland, 1987; Sarandón, 2002; Duran et al., 2015). The 2030 Agenda was established to achieve society's transition (Iacobuţă et al., 2022). This system is used as a frame for the policies of many states at regional, national, and even global levels (Hák et al., 2016; Rey & Sachs, 2012). Sustainability faces uncertainties about its concept and how it should be assessed, mostly because of the interlinkages with other SDGs (Spiller, 2016b; Weststrate et al., 2019). Although there is an entire goal dedicated to water, there is an overall lack of understanding of the role of water in contributing to other SDGs (Guppy et al., 2018; Tickner et al., 2016). The interlinkage between SDG6 and others is unclear in Agenda 2030, leaving this task to practitioners and local governments (di Vaio et al., 2021).

All the goals are interrelated and usually, SDG6 is the one with the most links (Coopman et al., n.d.; Weitz et al., 2018). Despite this, different methods and linkages defined by different researchers were defined to study the synergies and trades-off among SDGs. Many researches show in common that (Perez et al., 2020): (a) some interlinkages are stronger than others; (b) Some interlinkages are explicit, while others can be unclear; (c) some interlinkages can have a positive impact on achieving certain SDGs and others can be negative (make compliance difficult), and (d) water resources are mentioned in the target of a certain goal (Alcamo, 2018). The interlinkages have been studied from a target level (International Council for Science, 2016; Karnib, 2017a), goal level, and even statistical analysis of indicators on a country and global scale has been made (Alcamo, 2018; Pradhan et al., 2017).

There are more synergies (positive impacts) between SDGs and water (Ho & Goethals, 2019). However, some negative correlations represent some difficulties in achieving certain SDGs through the improvement of water quality, like in the water-energy nexus (Alcamo, 2018; Karnib, 2017b). On the one hand, renewable energy can improve the efficiency of water systems and lead to low levels of water pollution (Allen et al., 2020; Hellegers & van Halsema, 2021). The use of renewable energy can reduce GHG emissions, thus the water supply system can be more environmentally sustainable. Besides, if the water systems used micro hydropower systems, the leakages are reduced and therefore, the intrusion of pathogens from outside to inside of the pipe is reduced (Besner et al., 2011). On the other hand, non-renewable energies can be a consequence of not improving water quality (McCollum et al., 2018).

In general, the SDGs related to food (targets 6.5 and 6. a), health (targets 6.2 and 6.3), land (target 6.a), and climate tend (target 6.6) to put more pressure on freshwater resources, and their impact is negative on achieving some of the SDG6 targets (Ho & Goethals, 2019). But also, these SDGs could be improved by boosting water systems because of their dependency on the water system's state (Karnib, 2017a, 2017b). SDG3 is one of the few that relates targets directly to water systems, which reinforces their connection (Hall et al., 2020). Regarding SDG5 (gender quality, Fig. 1) the lack of facilities forces the affected female

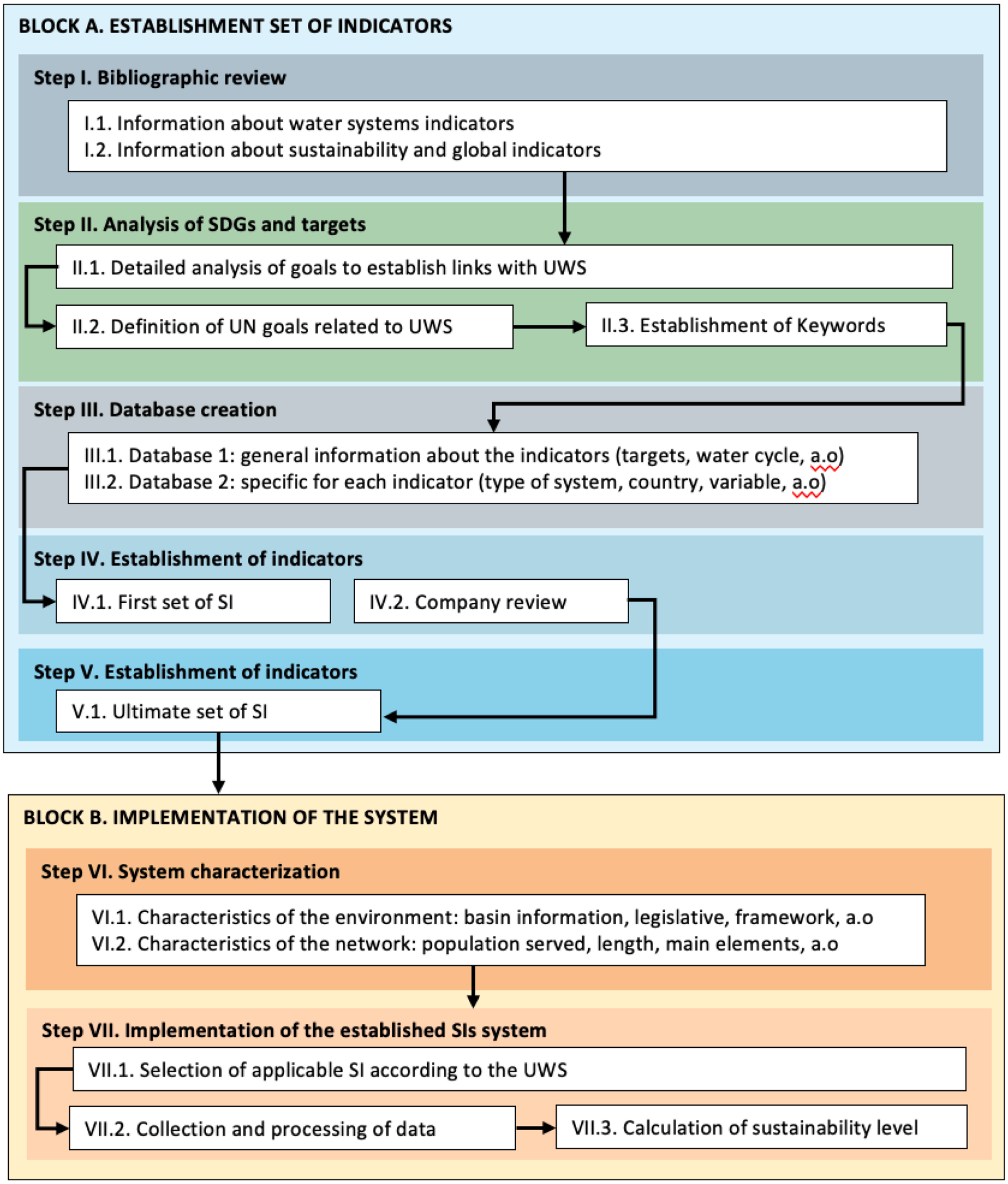

Fig. 1. The methodology followed for the establishment of the SI.

population to have practices far from what is sustainable (Pouramin et al., 2020). This leads in many cases to school absence for girls since there are no facilities that meet their hygiene needs (Pouramin et al., 2020). In these cases, it can be seen that the linkage between SGD6 and SDG5 also involves SDG4 (education).

The advance of SDG6 should support progress in economic indicators SDG8, SDG9, SDG10, SDG11, and SDG12 (Libala et al., 2021). Between SDG6 and SDG16, the synergies are about taking action to support good governance and management, financing of projects, research, and innovation (Libala et al., 2021). Water resources impulse the achievement of social and economic dimensions but those tend to be an obstacle SDG6 to being achieved (Ho & Goethals, 2019). The trade-off among SDGs can be either a limitation or an obstacle to achieving a goal (Nilsson Mans et al., 2016; Pradhan et al., 2017). When making decisions, the stakeholders should consider all types of linkages, even though they might be subjective, so in this way, it will lead to sustainable water cycle management. (Karnib, 2017b; (Hassing et al., 2009).

1.2. Sustainable indicators and methodologies applied to supply systems in cities

The indicators can evaluate quantitatively the fulfillment of the SDGs (INE - Instituto Nacional de Estadistica, 2021; Matos et al., 2018). They must allow the assessment of the different processes of the hydraulic systems from the infrastructure, operation, maintenance, and even the administrative part (Milman & Short, 2008). They must be applied to any type of system, regardless of its size, and be able to demonstrate some measure of sustainability (Lundin, 2003).

Many authors have evaluated and studied the sustainability indicators (SI) as tools and implemented them in study cases (Milman &

Table 2
Common sustainable indicators used by authors.

DIMENSION APPROACH	INDICATORS	REFERENCE
Health and hygiene	Acceptable drinking water quality Non-access to drinking water Number of waterborne outbreaks	Hellströ et al. 2000; Morrison et al. 2001; Romero et al. 2017; Milman et al. 2008; Maurya et al. 2020; Motevallian S et al. 2014
Social	Public acceptability; Public participation; Benefits for future generations Distance from water resources or treatment plant	Maurya et al. 2020; Motevallian S et al. 2014
Technical	Leakage; Sewer stoppage; Overflow; Flooding of basements Success with demand management and potential to reduce demand. Plan to manage water resources for the next 50 years; Reliability Water shortage Leakage energy	Hellströ et al. 2000; Longo et al. 2019; Lundin M et al. 1999; Maurya et al. 2020; Milman et al. 2008; Motevallian S et al. 2014; Morrison et. Al 2001; Vanham et al. 2018
Economical	Capital cost Operation and maintenance Sufficient funds to cover annual operations and maintenance costs Ability to generate new funds to cover additional capital costs The water provider has no outstanding debts (no threads of financial solvency) Economic pressure The annual cost of lost water and energy	Ávila et al. 2021; Hellströ et al. 2000; Romero et al. 2017; Maurya et al. 2020; Milman et al. 2008; Motevallian S et al. 2014
Environmental	Groundwater level N/P to water; $H+$ eq; CO2 eq; Cd, Hu, Cu, Pb, Al Use of electricity and fossil fuels Total energy consumption Use of fresh water and chemicals Potential recycling of phosphorus Annual freshwater withdrawal Use per capita per day Reused water Removal of BOD, P and N Sludge to landfill Energy recovery The volume of wastewater/ Pollution Load energy consumption Network energy efficiency Energy dissipation Conservative estimates of water supply for the next 50 years Water scarcity; Potential impacts caused by withdrawal; Water stress	Ávila et al. 2021; Hellströ et al. 2000; Llácer-Iglesias et al. 2021; Longo et al. 2019; Lundin M et al. 1999; Maurya et al. 2020; Milman et al. 2008; Motevallian S et al. 2014; Morrison et. Al 2001; Pardo M et al. 2013; Romero et al. 2017; Vanham et al. 2018

Short, 2008). Most of the implemented indicators focus on a single pillar, the environment dimension (Bagheri & Hjorth, 2007; Lundin et al., 2000). The most used and tested indicators are focused on the technical-environmental dimension (Lundin et al., 1999). When selecting the indicators, the criteria are not specified in many cases (Lundin & Morrison, 2002). Some references show how through the life cycle analysis (LCA), indicators can be chosen for the assessment of all areas of the urban water cycle (Hellströ et al., 2000). However, it has only sought to quantify the environmental impact of the UWS without considering other dimensions of sustainability (Herrera, 2019).

To consider all the sustainability dimensions, some authors propose analysis based on viability loops, although it only assesses whether the network is leading towards sustainability (Bagheri & Hjorth, 2007). Loops are a visual representation of the most important variables in a system and how they are interconnected (Bagheri & Hjorth, 2007). Another methodology to highlight is the DoS, which also seeks to cover all the dimensions of sustainability, although results are subjective for some authors (Guio -Torres, 2006). Even though methodologies exist, it is important to highlight the need to find a common basis for the assessment of sustainability in UWS (Guio -Torres, 2006).

Table 2 shows the SI commonly used by the reference to assess water systems. The indicators are fundamental for decision-making in the management of the systems. Knowing the status of the network can improve its operation. It is not just about improving the supply infrastructure, but also its management (Morrison et al., 2001). A supply can be managed in a good way, but not be optimal from a sustainable point of view (Lundin, 2003).

The review of the different published research showed the lack of compliance with indicators, which could be classified and proposed to evaluate the different targets of the SDGs applied to the water cycle involved in the cities. The use of a proposal, which could measure this evolution over time enables the possibility to improve sustainability and therefore, the improvement of the use of natural resources, mitigating climate change.

Appendix 1 shows the database, which includes 136 indicators. These indicators are based on reviewing the literature review (59 indicators) and the research includes 77 new indicators, which were defined according to the targets and SDGs. The definition of the new indicators considers the different variables, which could be measured in the water system. The appendix includes the different fields to associate with each indicator.

These fields are (i) ID indicator, which enumerates the indicator; (ii) Indicator name; (iii) ID_Goal, which define the number of a goal defined for each SDG by UN; (iv) ID_ SDG, which defines the SDG in which the indicator could support information to evaluate the target; (v) Sustainability Component, which describes the typology of the indicator between social, environmental, technical or economical; (vi) Water cycle, which defines where the indicator could be used; (vii) Study cases, which defines the number of case study find in this research; (viii) Reference, which indicates the reference or if the indicators are new. For each SDG, direct and indirect indicators were defined. The directs are related to explicit relations and the second ones are for those interfering relations that in a certain way contribute.

This research proposes a database of 136 indicators one was used by other authors and others are new and were defined in this research to guarantee to measure of the maximum number of targets of the SDGs linked to supply systems. The approach of the present research is to establish a methodology to set indicators that could assess the contribution of a UWS to the accomplishment of the SDGs, supporting this evaluation in a range scale defined by the values obtained in other case studies.

2. Methodology

The described methodology shown in Fig. 1 was followed to establish the system of indicators.

- **Step I.-** Bibliographic review. Information was sought on indicators that are implemented in UWS. The bibliographic review also consisted of the research of information about sustainability related to hydraulic systems. Appendix 1 shows the 136 indicators. A deep review was developed analysing the variable of the different

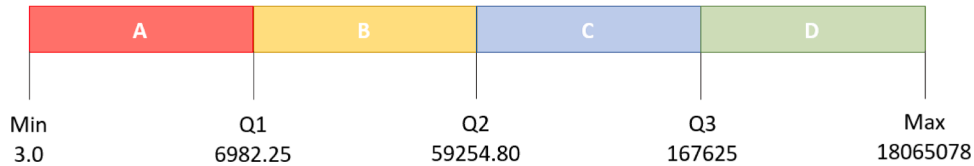

Fig. 2. Example of quartile for Indicator 24.

indicators found in the review. The chosen indicators were 59 because the rest of the indicators had variables, which could not be applied to the water system applied to the different targets of the SDGs. The proposed indicators (77) were defined considering the goal of the different targets of the SDGs. These new indicators used variables, which could be measured and/or evaluated in the management of the water systems. The appendix includes the different fields to associate with each indicator.

- **Step II.-** After the bibliographic review, a detailed analysis of the SDGs and targets was carried out. The definition of each of the goals established by the UN for each objective was studied. The concepts and measurement variables for each SDG and indicator were analyzed. This analysis included the development of a relationship between UWS and each SDG. It also defined SDGs targets related to urban networks. Different keywords were established based on the linkages defined and the analysis of the background. Indicators can later be established considering these keywords. They make it possible to encompass the characteristics and concepts of each goal, as well as its measurement variables and relationships with the SDG targets.
- **Step III.-** Database development. A database was created based on information and data collected from the literature review. The indicators defined in Step I were linked to other case studies. The database was completed using published data on the different variables of the defined indicators. The search also considered the reference values to evaluate the evolution of the different indicators in the following steps.
- **Steps IV and V.-** Establishment of indicators. Considering the goals of the SDGs related to water systems, the previously defined keywords, and the database created, the next step was to determine those indicators that allowed the measurement of each goal. Once a preliminary set of indicators was established for each SDG, a detailed review process of each one of them was started in conjunction with the company. This was done to be able to determine those indicators that allowed measuring sustainability from the list.

For this, meetings were held with staff from different areas of the water company to review the indicators associated with each SDG based on management or the different processes carried out in the company. In this review process, even some relationships between the goals and the water systems that had already been established in previous steps were redefined.

For the implementation of the established system of indicators, it is proposed to follow the processes of part 2 in Fig. 1. In **step VI**, it was identified the state of the environment and the network. Information about the basin, legislative framework, population served, network lengths, i.a., was collected.

For **step VII**, the indicators according to the characteristics of the network must be selected from the defined set. A list of the reasons why it was not possible to obtain data and therefore was not possible to measure certain indicators was also established. Then, it is proposed to calculate the level of sustainability, classifying it in A, B, C, or D. The classification aims to label the sustainability similar to the energy efficiency labels, according to the data and quantiles. This classification could be used when the networks are similar if water managers want to compare water systems between them. However, the main goal of the proposed procedure is to evaluate over time the water system. This evaluation allows water managers to check if making decisions cause positive impacts on sustainability and the achievement of the different targets of SDGs.

For this classification, the values were extracted from the references found in Step I and the data gathered from the company. The data extracted from the bibliography proceed from different countries (both developing and developed). The levels are based on mobile ends and quartiles. First, all the reference values were grouped according to the results for each indicator. Then, for each indicator that data was split into quartiles, to be able to divide the series equally into four levels. Maximum and minimum quartiles were calculated, then i.e., label D refers to the first quartile (minimum value) and it represents an excellent level, best results.

Mobile ends and quartiles were used to classify sustainability levels into A, B, C, or D. For each indicator the data was split into quartiles, to be able to divide the series equally into four levels. The reference values of an indicator were ordered from smallest to largest and then the 25%, 50%, and 75% quartiles were obtained. To calculate the quartiles, the following formula is applied:

$$Q_k = \frac{k(n+1)}{4}$$

In which, Q_k indicates the position of the value of the k quartile.

The first quartile which indicates the minimum value up to 25% of the data, is level D, indicating the lowest result that can be obtained. Level C indicates up to 50% of the data and level B 75%. Level A includes values between 75% and the maximum to be obtained. As an example of the above, for indicator 024 (energy recovery), Fig. 2 represents the levels of sustainability.

The level is referred to indicator showing level A as the minimum values and level D maximum values. Therefore, if a water system reached level A in leakage is the best and it reaches level A in renewable energy used it is poor.

Based on the previously established quartiles and levels, only for the SDG6 indicators, the level of sustainability was defined for each case study. Each case was taken separately, and considering the data, the indicators that could be applied were determined. For each indicator, the level of sustainability was defined by placing the value of that case in the ranges of the quartiles defined and thus setting its level. This process was done for each indicator and each case.

The letters represent a quantitative measure. As the individual results of each indicator turn out to be a letter, a number was assigned to each letter (A:1, B:2, C:3, and D:4). This was done to be able to determine the average of all the results of the indicators for each case study. With the average, a general level can be determined for a specific case. The value returned from the average was then represented again with the letter corresponding to the level (A, B, C, or D). This process was carried out for each of the case studies.

The statistical method of quartiles and mobile ends was suggested since there are not much historical data from the case study. Thus, the same system (for example, a supply) will be able to feed its level database with more and more information, and, said, the extreme values would be recalculated based on the amount of data. The evaluation by levels was carried out just for SDG6.

With the results, measures can be proposed to improve management leading to sustainability. These actions can be focused on improving the level of a single SDG or working on all of them little by little.

Fig. 3. Case studies (a) Global; (b) Specific to SDG6.

3. Materials

3.1. Global values

Fig. 3a shows the different case studies by country while Fig. 3b shows the case study used to analyze the SDG6 in which the information was obtained from almost 100 different case studies and using around 300 data to be processed.

The case studies were different in size, population coverage, and type of water distribution. Almost 11%, 11 cases, were from the agriculture networks and the 82% left was from urban water systems. Also, they were not managed by the same company. The countries where the most data was collected were Spain and Italy (20 and 11 cases, respectively). On average, 3 cases were found by country. Figs. 3a and 3b show the number of case studies found by country.

3.2. Company implementation

The methodology was also applied in a specific case study in some water distribution networks (WDN) in the East of Spain. All of them are managed by the same company. This was done to test the methodology not only on a global but also on a specific level. It was possible to collect around 840 data from the company. The information was representative not only of SDG6 but also of others.

Regarding the characterization of the environment of the network, in general, the basin where the networks are developed is the Júcar. It has an area of 42,988 km^2 and includes 8 large aquifers. The main sources for the networks are the Júcar and Turia rivers, as well as some wells. For 80% of the population of the basin, the company provides its supply services. The main uses of water are irrigation (80%), urban (16.5%), and industrial (4%). The proposed methodology is based on SDG, therefore, it could be applied to both urban and irrigation systems because it is based on indicators, which are defined using variables measured by water managers. Besides, the water company supplies both

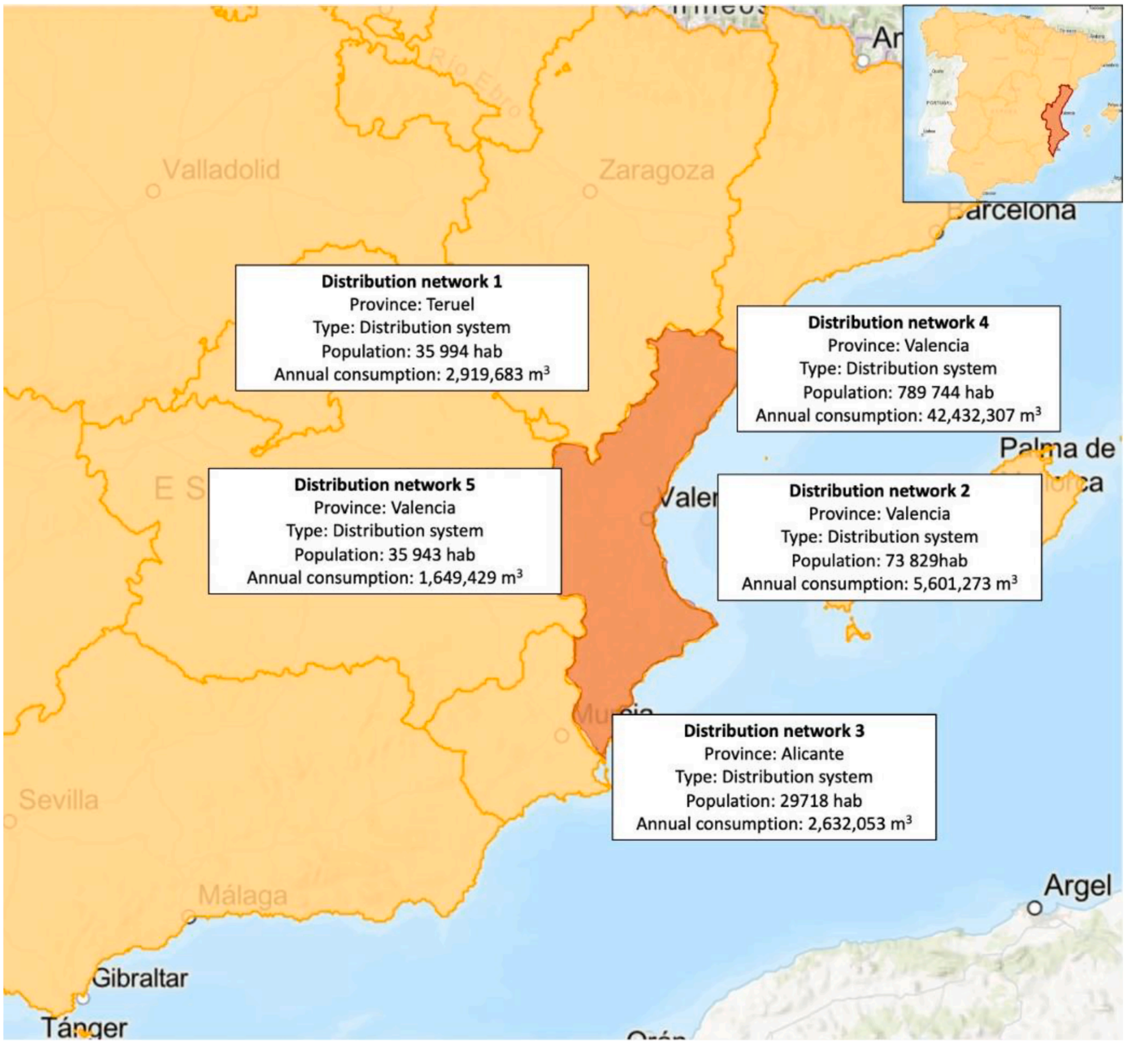

Fig. 4. Case studies from the company in Valencia, Spain.

irrigation and water supply systems.

It should be noted that the company's greatest advance is its remote reading system (58% of the network) and real-time monitoring through remote control. This system has remote stations and measuring instruments that allow manoeuvres to be carried out on certain hydraulic elements for the control of the network. The localization of the analyzed distribution systems is summarized in Fig. 4. Each case study is defined by a distribution system from 1 to 5. Each distribution system includes the water distribution of each case study and general information was included to characterize the supply system.

The data have been referenced for this research analysis.

Regarding the company reviews, 9 interviews were conducted with different water managers. Those meetings were with different areas of the company such as administrative, technical, environmental management, customer service, and human resources, among others. Although the number of interviews is low, the methodology establishes indicators that allow managers to develop strategies to evaluate those for which data are available and to develop improvement plans to increase the number of variables measured so that new indicators can be incorporated into the evaluation. Therefore, the applicability of the methodology can be used in any case study.

A classification was established distinguishing the difficulty in data collection and the possible reasons why certain indicators could not be applied. The data not obtained was mainly because so far, the company did not carry out such measurements, as in the case of the residual chlorine indicator, the average distance to the source and population with restrictions. If Appendix 1 is analyzed, the 136 indicators need above 180 variables to be evaluated. The knowledge implies developing different action as measurement, data acquisition, data reading, and data analysis, among others. These actions require a cost for the company or difficulty that causes them to be unfeasible and therefore, the company cannot assume their measurement and therefore, be able to evaluate these indicators. Increasing the number of indicators to be evaluated will increase the operating costs of companies and therefore their implementation should be gradual. Table 3 shows the main argument because the company cannot know this variable, and therefore, the analysis of the indicator. These arguments were answered in the interviews.

Table 3
Arguments for the lack of data SDG6.

ARGUMENTS FOR THE LACK OF DATA	
A	Cost of information (not profitable)
B	Data protection (confidentiality)
C	High acquisition time
D	Measurement time (scale)
E	Third-party data
F	Does not apply to the case (location)
G	Type of measurement, not performed
H	Others

Table 4
SDGs associated with targets, which could be evaluated in water systems according to the definition of the targets by the UN.

SDG	Name	Targets associated	Description
1	End poverty in all its forms everywhere	1.1.	By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day
		1.4.	By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.
		1.5.	By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.
		1.a.	Ensure significant mobilization of resources from a variety of sources, including through enhanced development cooperation, to provide adequate and predictable means for developing countries, in particular least developed countries, to implement programmes and policies to end poverty in all its dimensions.
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.1.	By 2030, end hunger and ensure access by all people, in particular, the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.
		2.2.	By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons.
		2.3.	By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.
		2.4.	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
		2.a.	Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks to enhance agricultural productive capacity in developing countries, in particular least developed countries.
3	Ensure healthy lives and promote well-being for all at all ages.	3.1.	By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births.
		3.2.	By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1000 live births and under-5 mortality to at least as low as 25 per 1000 live births.
		3.3.	By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.
		3.8.	Achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all.
		3.9.	By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.	4.4.	By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship.
		4.5.	By 2030, eliminate gender disparities in education and

(*continued on next page*)

Table 4 (*continued*)

SDG	Name	Targets associated	Description
			ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations.
		4.7.	By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and culture's contribution to sustainable development.
		4.a.	Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all.
		4.b.	By 2020, substantially expand globally the number of scholarships available to developing countries, in particular least developed countries, small island developing States and African countries, for enrolment in higher education, including vocational training and information and communications technology, technical, engineering and scientific programmes, in developed countries and other developing countries.
5	Achieve gender equality and empower all women and girls.	5.1.	End all forms of discrimination against all women and girls everywhere.
		5.4.	Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate.
		5.5.	Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life.
7	Ensure access to affordable, reliable, sustainable and modern energy for all.	7.1.	By 2030, ensure universal access to affordable, reliable and modern energy services.
		7.2.	By 2030, increase substantially the share of renewable energy in the global energy mix
		7.3.	By 2030, double the global rate of improvement in energy efficiency.
		7.a.	By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology
		7.b.	By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular, least developed countries, small island developing States and landlocked developing countries, by their respective programmes of support.
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.1.	Sustain per capita economic growth by national circumstances and, in particular, at least 7 percent gross domestic product growth per annum in the least developed countries.
		8.2.	Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labor-intensive sectors.
		8.3.	Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalisation and growth of micro-, small- and medium-sized enterprises, including through access to financial services.
		8.4.	Improve progressively, through 2030, global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation, by the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead
		8.5.	By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons

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Table 4 (*continued*)

SDG	Name	Targets associated	Description
			with disabilities, and equal pay for work of equal value
		8.6.	By 2020, substantially reduce the proportion of youth not in employment, education or training
		8.8.	Protect labor rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.	9.1.	Develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
		9.2.	Promote inclusive and sustainable industrialization and, by 2030, significantly raise the industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries
		9.4.	By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action by their respective capabilities
		9.5.	Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending
		9.a	Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States
10	Reduce inequality within and among countries	10.1.	By 2030, progressively achieve and sustain income growth of the bottom 40 percent of the population at a rate higher than the national average
		10.2.	By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status
		10.3.	Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard
		10.4.	Adopt policies, especially fiscal, wage and social protection policies, and progressively achieve greater equality
		10.5.	Improve the regulation and monitoring of global financial markets and institutions and strengthen the implementation of such regulations
		10.b.	Encourage official development assistance and financial flows, including foreign direct investment, to States where the need is greatest, in particular, least developed countries, African countries, small island developing States and landlocked developing countries, by their national plans and programmes
11	Make cities and human settlements inclusive, safe, resilient and sustainable.	11.1.	By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums
		11.3.	By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries
		11.4.	Strengthen efforts to protect and safeguard the world's cultural and natural heritage
		11.5.	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to the global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
		11.6.	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
		11.b.	By 2020, substantially increase the number of cities and human settlements

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Table 4 (*continued*)

SDG	Name	Targets associated	Description
			adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels
12	Ensure sustainable consumption and production patterns	12.2.	By 2030, achieve the sustainable management and efficient use of natural resource
		12.4.	By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, by agreed international frameworks, and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment
		12.5.	By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse
		12.6.	Encourage companies, especially large and transnational companies, to adopt sustainable practices and integrate sustainability information into their reporting cycle
		12.8.	By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
		12.a.	Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production
13	Take urgent action to combat climate change and its impacts.	13.1.	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
		13.2.	Integrate climate change measures into national policies, strategies and planning
		13.3.	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.	14.1.	By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution
		14.2.	By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and taking action for their restoration to achieve healthy and productive oceans
		14.3.	Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.	15.1.	By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements
		15.4.	By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, to enhance their capacity to provide benefits that are essential for sustainable development
		15.5.	Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	16.1.	Significantly reduce all forms of violence and related death rates everywhere
		16.6.	Develop effective, accountable and transparent institutions at all levels
		16.7.	Ensure responsive, inclusive, participatory and representative decision-making at all levels
		16.10.	Ensure public access to information and protect fundamental freedoms, by national legislation and international agreements
17	Strengthen the means of implementation and revitalize the global partnership for sustainable development	17.3.	Mobilize additional financial resources for developing countries from multiple sources
		17.5.	Adopt and implement investment promotion regimes for least developed countries
		17.7.	Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms, including concessional and preferential terms, as mutually agreed
		17.16.	Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share

(*continued on next page*)

Table 4 (*continued*)

SDG	Name	Targets associated	Description
			knowledge, expertise, technology and financial resources, to support the achievement of Sustainable Development Goals in all countries, in particular developing countries

4. Results

4.1. Establishment of indicators

To ensure that the indicators covered all the SDGs, the relationships between the SDGs and the water systems were first obtained. Table 4 presents the different SDGs related to each target. This analysis established the connection of the 74 targets considering 17 SDGs. As an example of linkage found with SDG5, urban water systems can contribute to target 5.1. by ensuring equal working conditions for women. Likewise, by improving the coverage of the networks, it is possible to ensure sanitary and hygiene facilities for both women and girls.

The database which is summarized in Appendix 1 establishes different keywords for the different indicators defined as well as targets. It enables the development of an interactive map to define the different connections between SDGs, targets and indicators. This analysis is shown in Figs. 5 and 6. This analysis enables the connection of different SDGs and targets by common topic (keyword) and therefore, it enables the evaluation of different targets. For example, if one wants to analyze the presence of the female gender, the map developed (Fig. 4) shows that SDG6, SDG12 and SDG5 are directly related while Fig. 5 would show the relationship of targets.

The research defined a database, which contains 136 indicators. These are established in Appendix 1 and could be classified according to area operation in the water systems. It implies there are indicators which could be used in different areas (i) Supply systems: water catchment, water purification, and distribution; (ii) waste-water treatment; and (iii) sanitation distribution systems. This classification was established according to the following 110 indicators for supply systems, 87 indicators for water treatment systems and 100 for sanitation systems. Fig. 7 shows the number of indicators established for each SDG, classified by type of system.

The indicators were classified based on the area of sustainability to which they contribute. Some indicators are assigned to more than one area. In general, 49 indicators are for the environmental dimension, 9 for economic, 68 for social, and 54 for technical. Similarly, for SDG6, 40% of the indicators were environmental, 30% technical, 28% social, and 12% economic (Appendix 1 shows this sustainability area for each indicator). Each specific indicator (SI) was related to different indicators when the variable of this indicator could be supported by the keyword connection map. The area water treatment includes wastewater treatment, sanitation includes the caption and water treatment to be useful the water for the population and/or irrigation and the supply includes the distribution of the resource by water systems.

Making this similar classification for each of the SDGs, it is possible to verify that each one was focused on its main pillar of sustainability. For example, SDG 10 is more focused on the social sphere. For this, 87% of the indicators were social and 13% environmental, there are neither economic nor environmental due to the nature of the SDG. Furthermore,

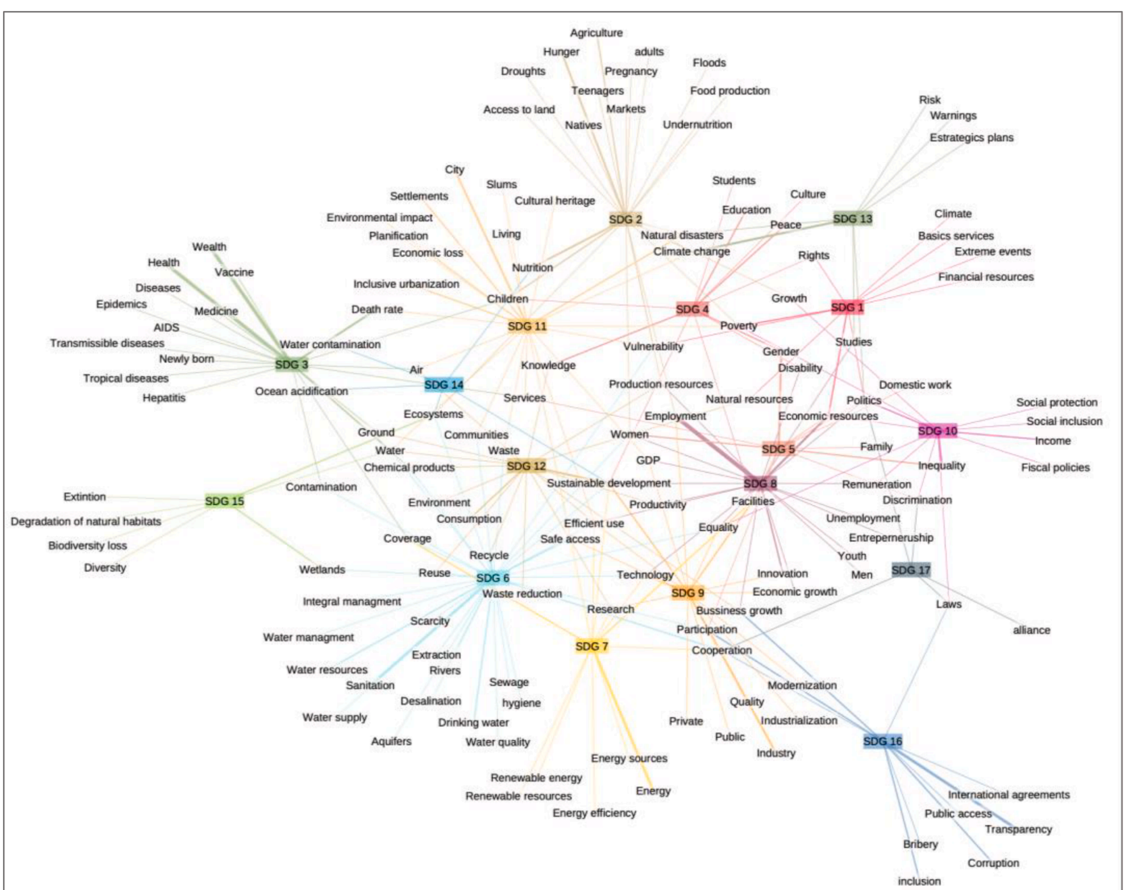

Fig. 5. Keywords for each SDG.

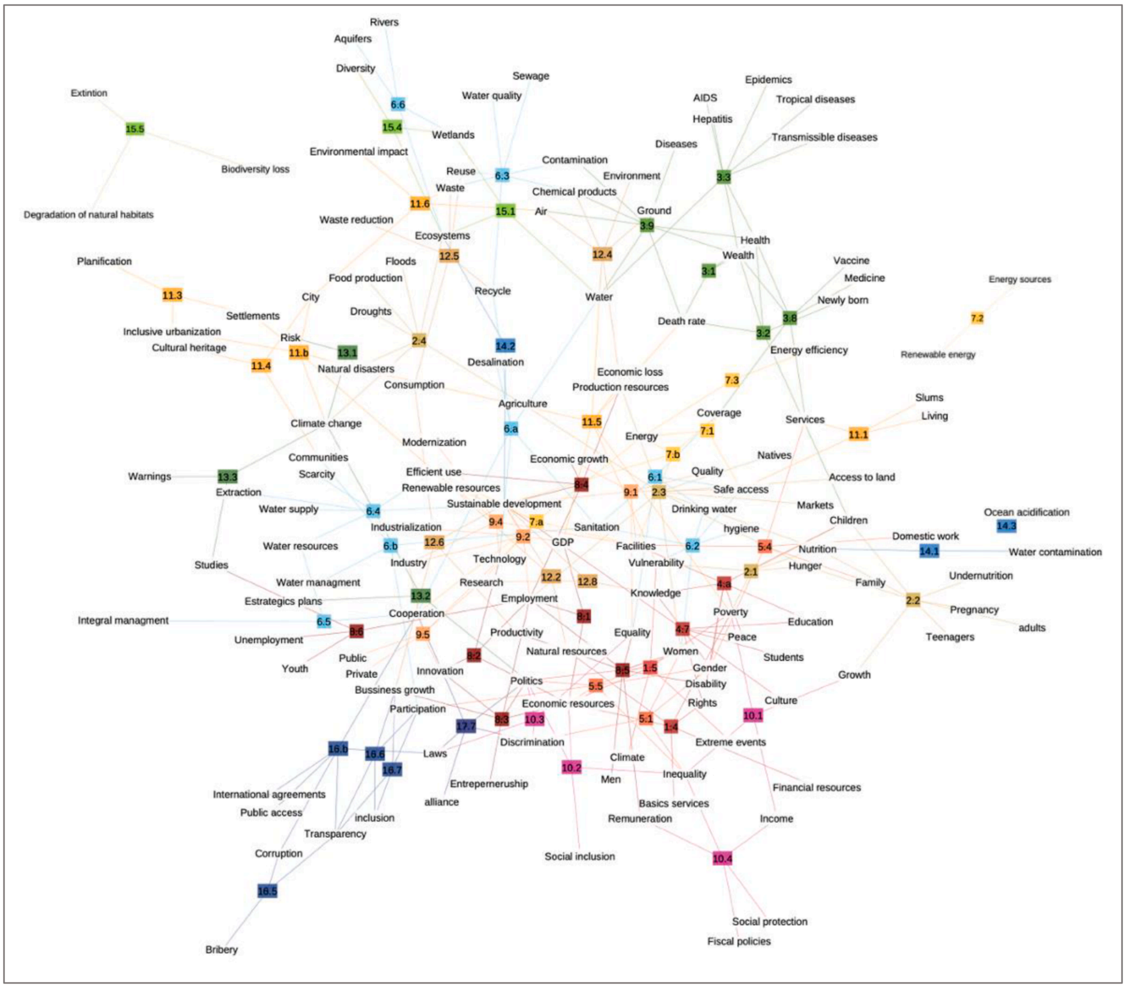

Fig. 6. Keywords related to each SDG target.

there are some SDG that involves all the areas of sustainability. For SDG12 53% of the indicators are environmental, 25% are technical, 20% are social and only 2% are economic.

4.2. Macro scale implementation of results

4.2.1. Global values – defining levels of sustainability

Based on the data found from the UWS, the parameters for the level of sustainability were established for the indicators implemented. These levels were made with moving averages based on the reference data (93 cases study defined in Appendix 1) obtained in the literature review. It was possible to define the levels only for some of the SDG6 indicators since only global values for this were obtained. Nevertheless, the goal of the analysis was not to compare them, because the systems are different in terms of developments and/or development of their society. However, the analysis showed the variability and the difference in terms of the sustainability of the different countries. Once the analysis was developed and the indicators were chosen, the methodology could be evaluated the evolution of these indicators if different annual values were published by the different public entities. Table 5 shows the indicators used.

Fig. 8 shows the defined parameters for the indicators implemented were defined. Some indicators that have a higher result in red can be observed, mostly those related to waste and energy management, and the operation of the UWS. This highlights a challenge for all the UWS that were reviewed, in the management of the services by improving or taking strategies for the care of the resources. Fig. 8 considers all case studies. It implies the comparison is difficult in some of the indicators because of the topology and characteristics of the water network (e.g., total energy). However, it helps to understand the high energy values used by water systems. The best application of the methodology requires the evaluation of the different indicators over time in each water system.

Based on the defined levels, it was possible to measure the level of sustainability for each case study. Fig. 9 shows the level obtained by country according to the results for each water distribution system based on the place that was consulted in the references. A general level was considered when the different indicators were evaluated to show a sustainability level. It can be seen that in general, most of the countries have a level B or C, which represents that there is plenty of room for improvement. According to this preliminary analysis, the countries with the best results are Mexico, Turkey, and Denmark.

In general, for all the case studies, 43% of them have a "B" Level and 33% have a "C" Level (Fig. 10). Only 10% obtained the highest score, the "D" Level. It can be seen that globally, there is plenty of room for optimizing the management of UWS from a sustainable point of view. It should be mentioned since all the case studies differ in size, this leads to that when compared to the rest, percentages are outside the range or very low.

4.3. Micro scale implementation

Considering the typology of implemented networks, 110 indicators could be implemented, of which only 97 were applied to the case. The reasons why some particular indicators such as residual chlorine, and

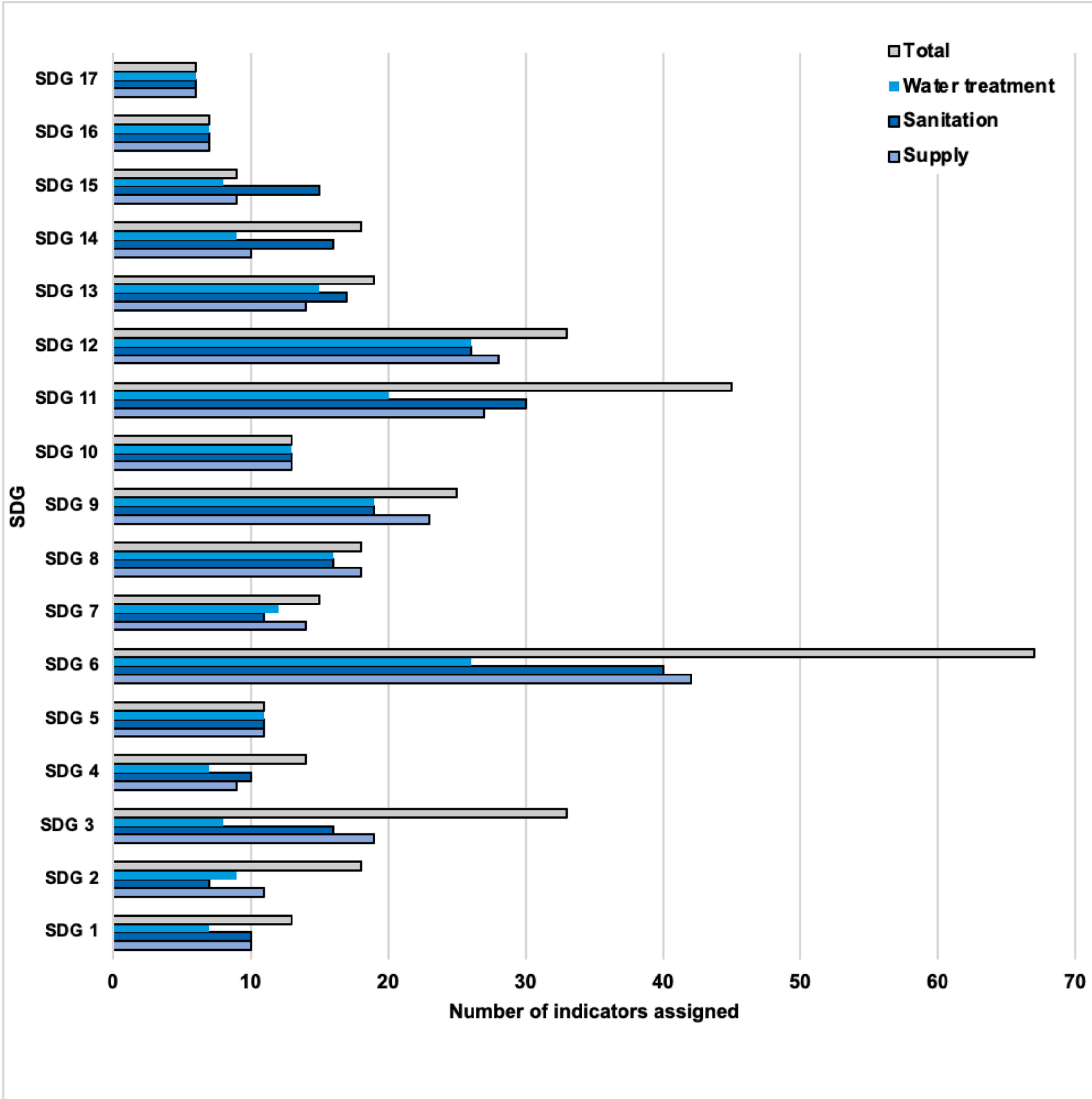

Fig. 7. Quantity of SI determined for each SDG.

Table 5
Amount of reference cases for each indicator.

	ID	Indicator
Social / Technical sustainability	2	Water quality (anomalous test)
	9	Coverage of the service
	27	Use of fresh water
	39	Customer awareness
	88	Access to company information and water issues
	67	Total energy used
	35	Leakage
Economical Sustainability.	87	Associations
Environmental sustainability	43	Renewable energy generated by water companies
	49	Greenhouse gas emissions
	24	Energy recovery
	69	Contingency plan
	83	Actions to reduce water footprint
	104	Sustainability/Environmental licenses or certificates
	18	Reused water
	32	Compliance with catchment licenses

social programs, among others, could not be applied, is mainly because the data related to these were not measured. Additionally, some indicators did not apply to the case, such as the average distance to the access point and the population with restrictions. These were not applied because this data is usually more relevant in developing territories. Fig. 11 indicates the number of indicators of each SDG implemented for the company case.

Fig. 12 shows the contribution of the water company to each SDG. For SDG14 and SDG15, a great difference was observed between the number of indicators to be implemented and the data obtained since the company did not carry out measurements for some of the variables. Fig. 13 shows the contribution of the compliance of the SDGs in which, 106 indicators of the total indicators (135 - 76.30%) were included in this analysis.

When SDG6 was analyzed in the case study, it included 67 indicators. 38 indicators of these 67 (56.72%) could be applied in the case study but only 16 indicators (23.88%) were used because the water company did not have measured data. The results of the SI for SDG6 show that the company contributes to all the related goals (Fig. 14). This same data can be obtained for the rest of the SDGs and would be relevant when taking actions that can be aimed at general improvement or towards those objectives where there is a greater or lesser contribution to the

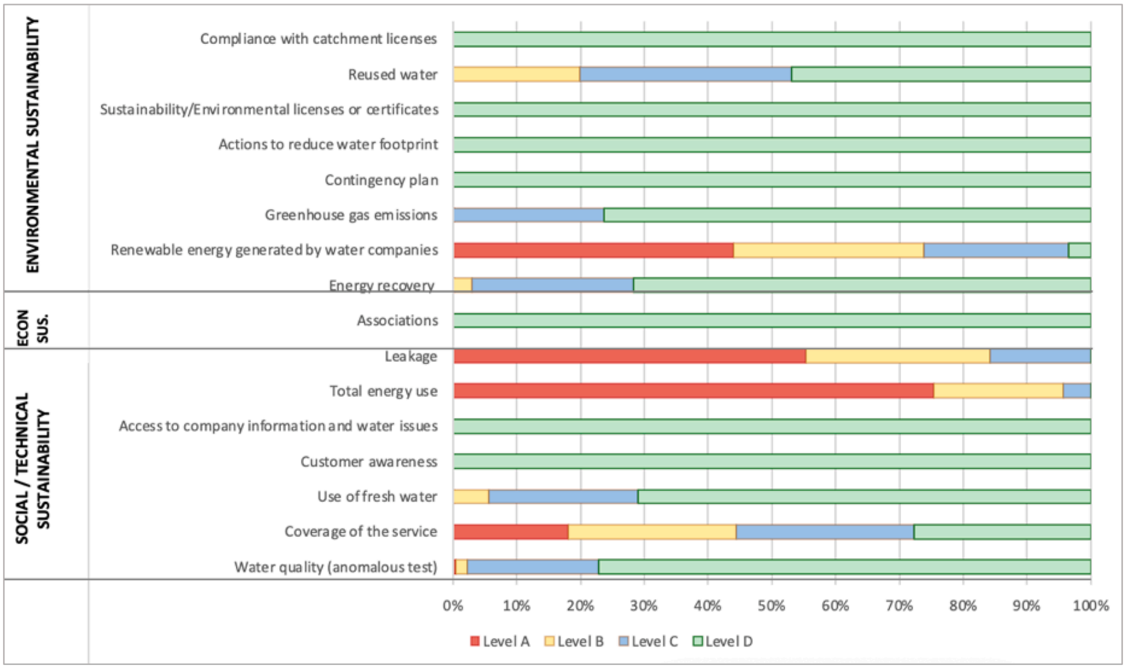

Fig. 8. Defined parameters for the SI implemented.

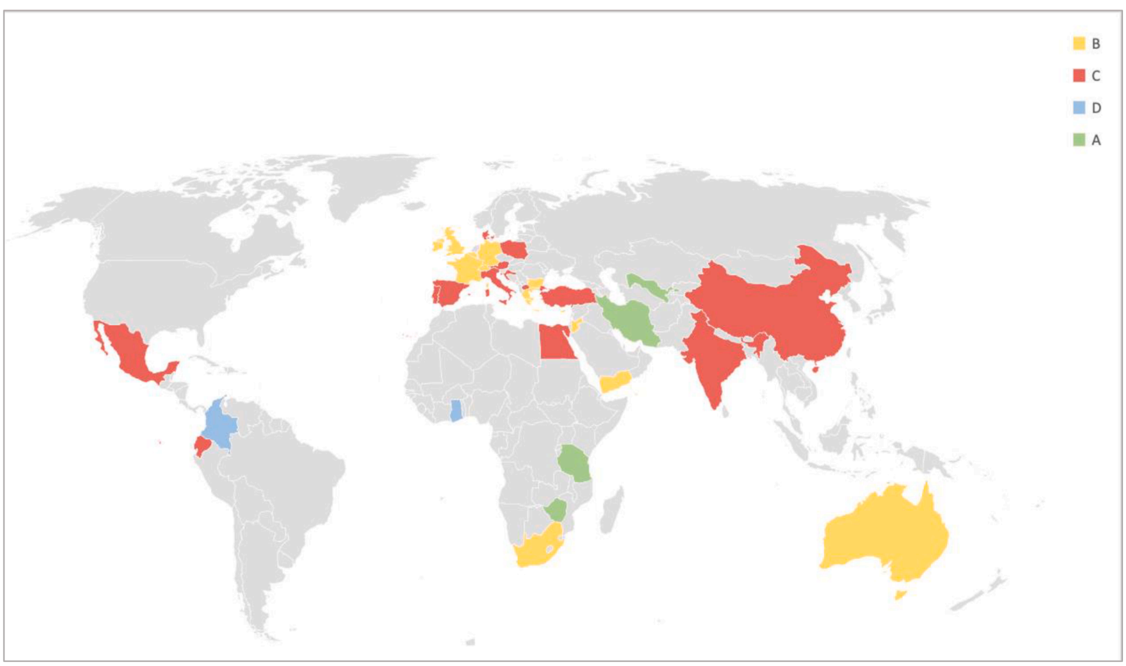

Fig. 9. Levels obtained by country.

goals. The use of the methodology showed the company the need to increase the number of variables measured and/or analyzed to improve the number of indicators to be calculated and, therefore, the targets to be evaluated in the SDGs.

At the corporate level of the case study, as far as SDG6 is concerned, the company obtains a D level in sustainability (Table 5). It is a good level, however, when looking at the specific case of the networks it obtained levels “C” or “B”, which give plenty of space for improvements. The upgrades can be made for example, in terms of greenhouse gas emissions, renewable energy, and the use of fresh water (Table 6).

On the other hand, the level of difficulty in data collection was measured. The results show that in general the variables related to the measurements were very easy to obtain. Therefore, it can be said that the indicator system meets the characteristics mentioned above such as its easy implementation (IWA et al., 2018)(IWA et al., 2018). The limitations of the methodology are based on the number of variables to be used. This number depends on the goals to be evaluated. Therefore, the economic cost of measuring the variables may mean that many indicators cannot be known even if they are of interest. For this reason, the methodology requires long-term planning so that an increase in the number of variables can be undertaken once the main indicators that are less difficult to evaluate due to cost or availability of data have been consolidated.

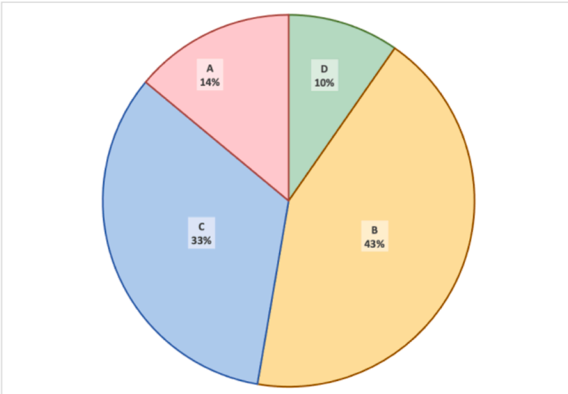

Fig. 10. Percentage of levels obtained for all the case studies.

5. Conclusions

This research established a methodology for analyzing compliance with the SDGs in urban water systems and implementing it in case studies in the Valencian Community. The obtained result was a set of 135 indicators applicable to any type of urban system that measures the contribution of water companies to the compliance of SDGs and their level of sustainability. This set of indicators may serve as a basis for an evaluation methodology and for the design of future supply networks.

Based on the results from the implementation, the management can lead to the promotion of sustainable development. Companies can improve at a general level all the SDG goals to which it contributes. Another option is to improve a single SDG (the one with bets or worse results) and the last option is to start an improvement plan based on more than one indicator. Also, from the sustainable level of the company, it can be served as an example, benchmarking, for the company itself or others for improvement. The more information there is on a sustainably managed supply, the level of sustainability of others, being lower, will allow them to take improvement actions that point towards safely managed practices.

It was observed that when establishing sustainability levels, the system is highly sensitive to the available amount of data. This means that a level established for a UWS can vary greatly depending on other data, either to improve or worsen. Hence, as an improvement of this methodology, the values of reference for each indicator might be separated depending on the size of the network, so in that case, the comparisons between UWS and the definition of the sustainability level could be more accurate.

This methodological proposal forms the basis for future research work that should include newly published case studies. In addition, the development of the methodology and its applicability to real cases will allow companies to determine which SDG targets they can assess; to know if they have sufficient data to assess them and to start designing future strategies that will allow them to implement techniques to improve their measurement of the SDGs. The number of measured variables in each case study as well as the difficulty to compare between different case studies limits the proposal. Future researches should be involved to define a normalized index, which could compare different countries between them.

Sustainability is the result of an improvement process that can be guided by sustainability criteria such as indicators. These show how far or close you are from the ideal point and will serve as the basis for

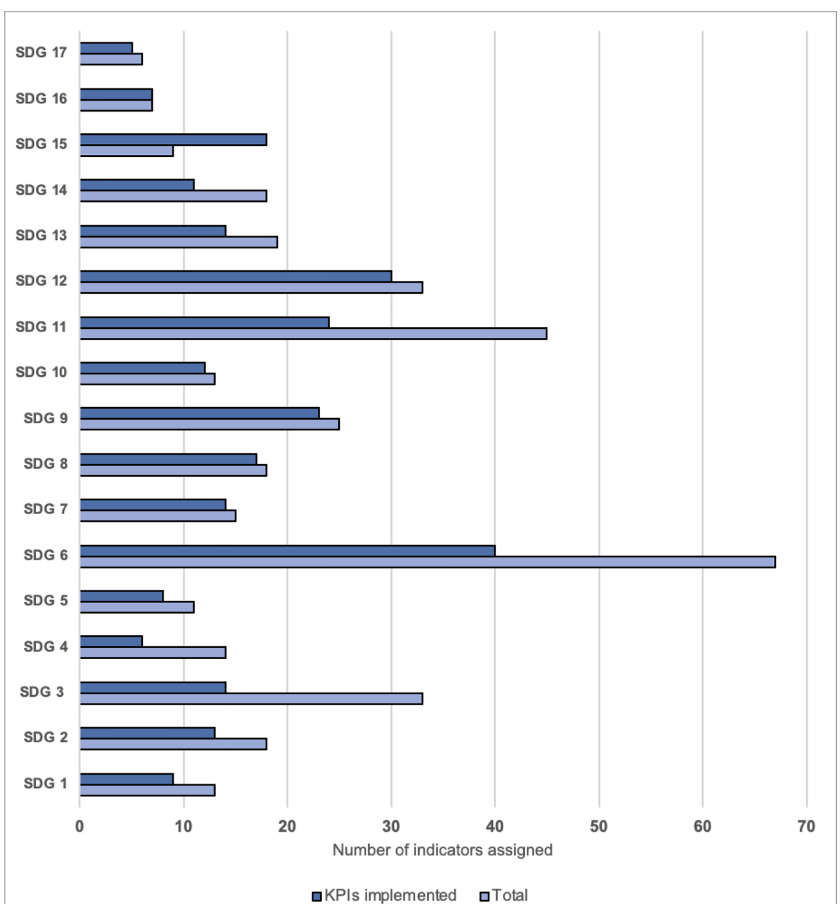

Fig. 11. Quantity of SI of each SDG implemented in the case study.

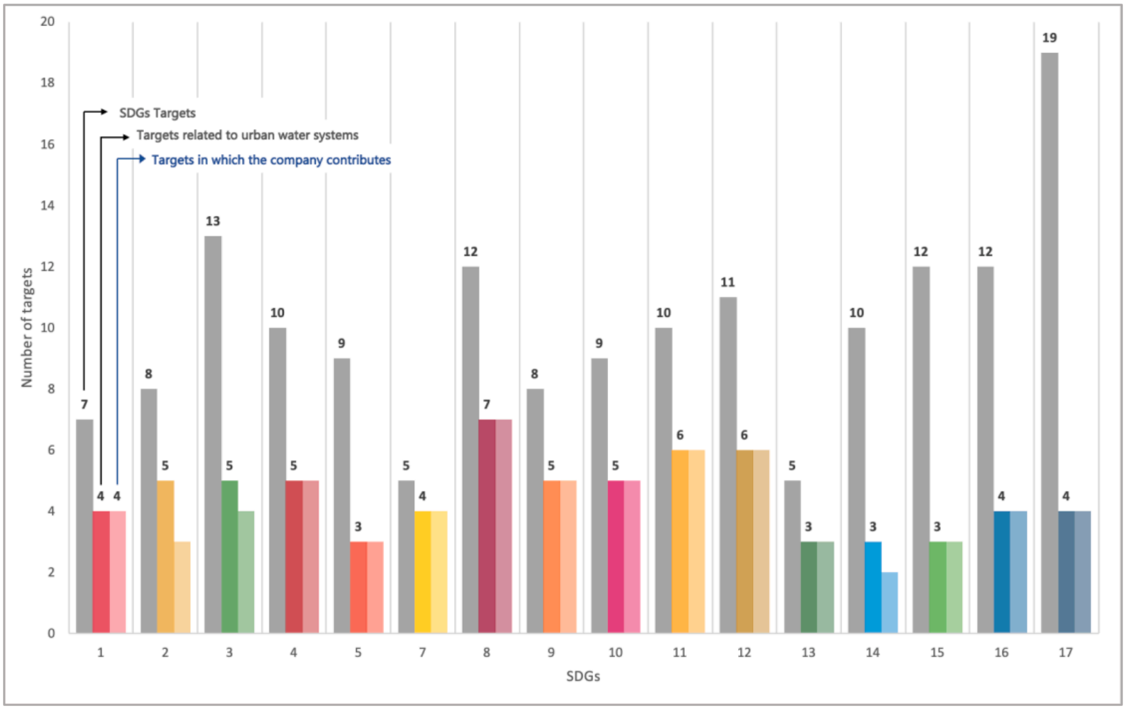

Fig. 12. Targets to which the UW company contributes by SDG.

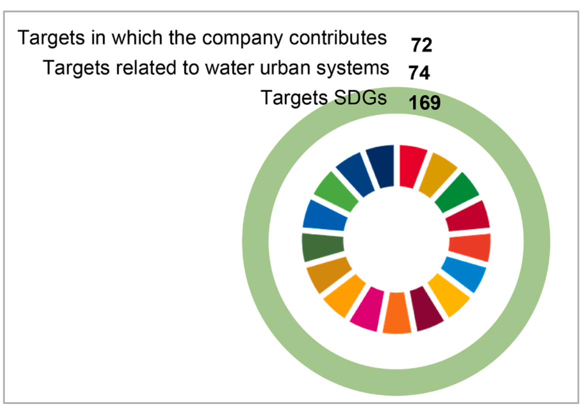

Fig. 13. Company contribution to the SDGs compliance.

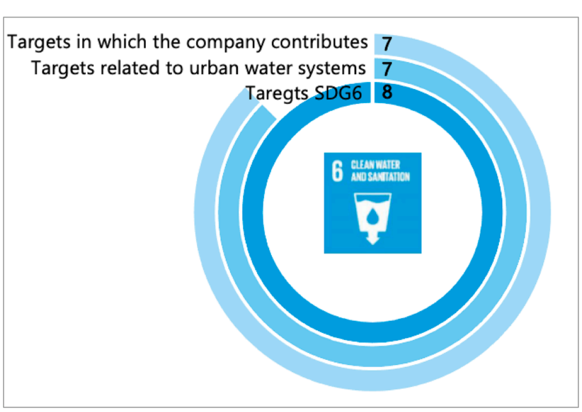

Fig. 14. Company contribution to the compliance of SDG6.

Table 6
Companys sustainability level for the SDG6.

Case study	Level
Company	D
Distribution network 1	C
Distribution network 2	B
Distribution network 3	C
Distribution network 4	B
Distribution network 5	B

decision-making. The SDGs are drivers toward the sustainable change needed for resources. For further research, it is proposed that the levels be evaluated for each SDG, not just DG6. Also, is hoped that the database can be fed with more information from developed and developing countries to have a standard for both types of systems. This work is open to research and turns out to be a hint of quality and development in hydraulic systems.

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.

Data availability

The data that has been used is confidential.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scs.2023.104704.

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