Assessment of the implementation of citizen science in a DPSIR model in the Campina de Faro aquifer system

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Abstract

Imminent climate change will exacerbate water issues in Portugal, and especially in the Algarve, such as sea level rise, decrease of precipitation and change in the groundwater levels. This fact combined with unsustainable practices that have been carried in the touristic and agricultural sector in the mentioned region, have caused problems in the groundwater quality and quantity in the Campina de Faro aquifer system. Thus, solutions must be sought for a better groundwater management and conservation. This study presents a DPSIR framework that intends to become a tool that can support future decision-making in the Campina de Faro aquifer. Three scenarios are modelled and compared: one actual state and two future situations under climate change, one that considers citizen science, and another one that doesn't. Pressures that are exerted in the aquifer are assessed along with their impacts in a normalizing unit (ton CO2 eq). In the future scenarios, forcing coefficients are input to evaluate first the effects of some climate change consequences (e.g., sea level rise), and later to determine objectives regarding stakeholders' participation in the information compilation, conservation, and management of the groundwater body. It was demonstrated that in the future, the CO2eq emissions associated with the activities carried out in the aquifer (e.g., groundwater abstractions for irrigation of touristic areas or crops) are going to increase in 12.3%. However, it was also found that it is possible to maintain the actual amount of emissions (28.59 mega ton CO2 eq), if there is a 19% drop in the groundwater abstractions, or replacement of water origin, including treated wastewater, in all of the activities in the region, and also a decrease of 19% in the groundwater pollution due to the percolation of pesticides and fertilizers. These reductions are targets that the thesis suggests, and that may be possible though stakeholders' engagement for participated water management.

Key Words: DPSIR framework, citizen science, stakeholder engagement, groundwater management, Campina de Faro aquifer system

Introduction and background

Portugal is one of the European countries most susceptible to desertification, fact that has been worsened in the past years due to climate change. This can be corroborated when looking at the data of precipitation and groundwater recharge of the past decade, that in both cases is lower than the average of the past 50 and 60 years respectively. The projections for the future are not promising neither. It is expected for the precipitation to continue decreasing in the south of Portugal for the 2050 and 2100 horizons, and thus, the recharge levels are likely to drop as well. Moreover, the sea level is estimated to rise in twelve centimeters for the year 2050 (Miranda, 2006).

On top, the region of Algarve has been experiencing an accelerated growth in terms of tourism and agriculture, which aggravates the hydrological unbalance in the region, because of the increased water needs. The known use for irrigation of agricultural areas represents 26% of total consumption in this water body, whereas the extractions for recreational and laser activities, among which stands out the irrigation of golf courses, account for another 28%. In total, the known extractions carried out in this groundwater body correspond to 65,3% of the long-term mean annual recharge, but the estimated extra volumes represent 144,8% of the long-term mean annual recharge(APA, 2012).

The development of the region in the farming sector has led additionally to enrichment of groundwater with nitrates, with average nitrate concentrations in the phreatic aquifer above 50 mg/L (APA, 2020). These elevation of concentrations has led the need to include part of the Campina de Faro (Faro subsystem) aquifer under the classification of "nitrate vulnerable zone" (Portaria n.º 164/2010, 16th March, in accordance with EU Council Directive nb. 91/676/CEE, 12th December).

On the other hand, the National Water Resources Information System (SNIRH by its acronym in Portuguese) is the only agency in charge of processing, validating, and disseminating all the information collected in the monitoring networks of the Portuguese Environmental Agency (APA by its acronym in Portuguese), and other local and regional entities. However, some gaps in the data that it's provided by this organization are found when browsing the website.

Furthermore, the groundwater governance and involvement of participants, can become a more challenging issue as there is as the access to this resource is in some cases simple as it is "available on site", which led to a decentralized management which carries along inequality because who has more technology and/or money can pump deeper and extract more water quantities. Therefore, a danger of overexploitation is always present and it affects in an inequitable way the communities. To withstand this matter, a centralized management would be a solution, however, it is known that groundwater monitorization is difficult because it is an "invisible" resource, licensing is prone to corruption, big users want to recover capital, among others, thus, another solution could be "self-regulation" from users which requires strong and continuous stakeholders' participation (Hoogesteger, 2015)

Therefore, there is a need for upgrading the management of the groundwater resources in the region, as well as improving the information. The project eGroundwater arises consequently, intending to cover both of these aspects: the sustainable management of the aquifer by involving citizen science and ICT (Information and communications technologies) as an enhanced information system.

The program also intends with this participatory approach, the assessment of the aquifer, and the later groundwater modelling in some Mediterranean regions, and among them, the Campina de Faro aquifer system. The participation of stakeholders in monitoring, collecting, and sharing data, and a better and more transparent information system are key issues for the eGroundwater strategy to develop improved hydrological models which are expected to lead to more sustainable management of the aquifer.

Hence, this study aims to help understand the causal relationships between the different driving forces acting in the territory, which generate pressure on the hydrologic systems, and the resulting environmental impacts. For this purpose, the quantitative DPSIR (Driving-Force-Pressure-State-

Impact-Response) model was use (EEA, 2003). Apart from the base scenario, reflecting current conditions, the analysis included the study of two different future scenarios, both of which take into account the climate change, but only one of them includes the participation of citizen scientists.

Thus, it intends to find the actual amounts of the pressures that have been exerted in the aquifer, in order to compare how much they would rise under the effects of climate change, and therefore, how could the citizen science involvement help to maintain the present values even when the aquifer will be affected by changes in precipitation, recharge, and sea level rise.

Study area

The study area of this thesis is the Campina de Faro aquifer system, which is located in the hydrogeological unit “Southern Mesocenozoic Rim” with an area of 86.4 km^2 in the district of Faro in the Algarve region, limited to the north by not very permeable deposits of Cretaceous, to the east by the city of Olhão, to the west by the Quarteira aquifer system, with a possible hydraulic connection between them, and in the south by the sea (Almeida, 2000).

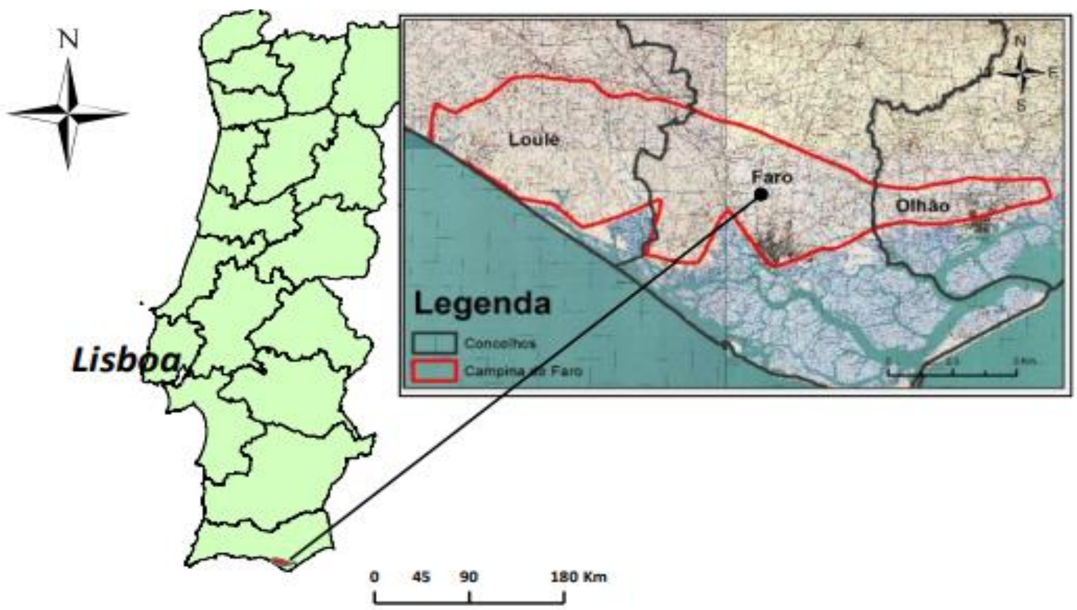

Figure 1 Location and delimitation of the Campina de Faro Aquifer. (Viegas, 2015)

The Campina de Faro aquifer is divided in two subsystems: Vale de Lobo, to the west, and Faro to the east. The first one accounts for an area of 32.41 km^2, and for the report year it had an approximate annual mean recharge in long term of 4.6 hm^3, and annual extractions of 5.86 hm^3 with great pressures from the golf and “others” sector. This has made the hydraulic head in this subsystem to decrease, being classified as “mediocre” quantitative state. (APA, 2016).

The Faro subsystem (53.99 km^2) has approximate mean annual recharge of 6.2 hm^3, and annual extractions of 3.66 hm^3. Thus, the hydraulic levels in this part of the aquifer have an increase tendency and the quantitative state of the groundwater body is “good”. However, regarding the qualitative state, the Faro subsystem continues being “mediocre” (APA, 2016).

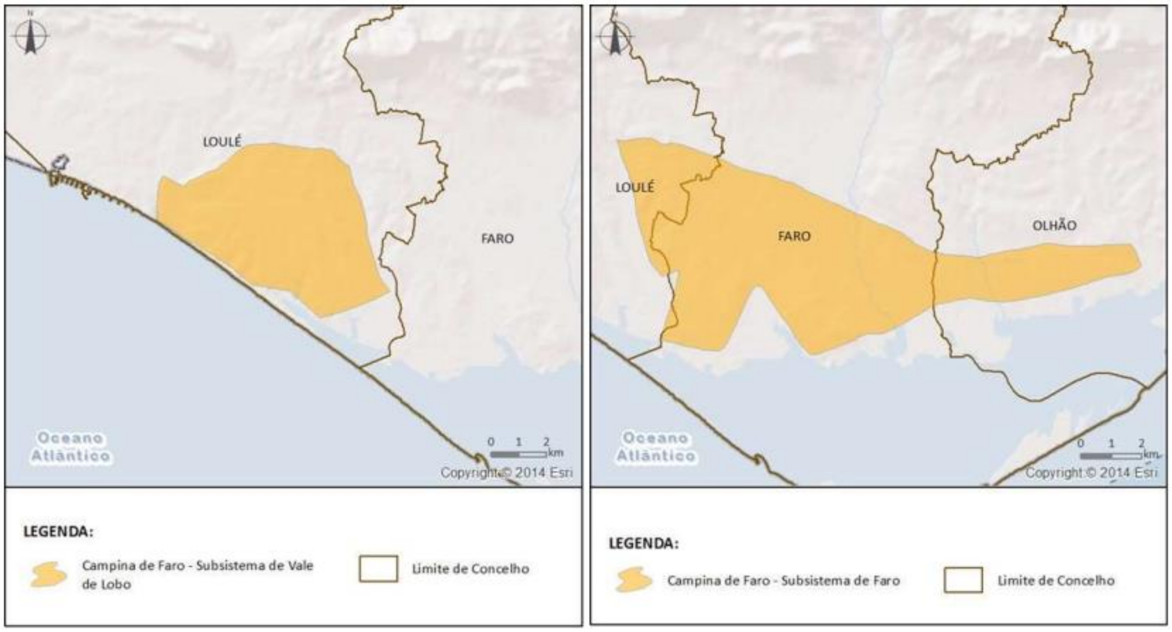

Figure 2 Campina de Faro water management subsystems of Vale de Lobo, on the left, and Faro, on the right (APA, 2016).

Moreover, Campina de Faro is constituted of two main aquifers in the aquifer system: a detritic phreatic porous aquifer on top of a multilayer confined carbonaceous aquifer, which are made independent by the presence of impervious formations. Moreover, give its heterogeneity, there are some parts that are fully dependent on the precipitation (APA, 2012). There has been an overexploitation of the aquifer over the past decades due to agriculture (easternmost part of the aquifer) and tourism, mostly due to golf resorts (westernmost part of the aquifer). These activities combined with the constitution of the system, have led to nitrate contamination in the east, and suspected seawater intrusion on the west (APA, 2012).

Three main types of drivers can be categorized as driving forces that affect the Campina de Faro aquifer system: tourism, urban areas, and agriculture. The first one, is strongly related to the large amount of golf courses in this region, for which the groundwater is the main source used to irrigate them, and the Campina de Faro aquifer accounts for around of 30% of this total water needs, destinating half of the extractions of the subsystem Vale de Lobo to this purpose (3.25 hm^3) (APA, 2020).

Urban areas are another driving force putting pressure in the groundwater quantity because the aquifer spreads over three municipalities: Loulé, Faro and Olhão, which coincide to be the most inhabited in the Algarve region, therefore, the generation of wastewater should be also considered, along with the water supply. However, it must be stated that the water from the Campina de Faro aquifer is not used by public companies for domestic water supply which use instead surface water and groundwater from other water bodies. Nonetheless, in our model, due to the production of tap water and treatment of wastewater are allocated to aquifer domain.

Finally, the agriculture activities, mostly concentrated on the eastern part of the aquifer (subsystem Faro) put pressure on groundwater quantity, being responsible in 2019 for 88% of the total annual water abstraction from this sector, amounting to 5.20 hm^3 (APA, 2020). On the other hand, agriculture also affects the groundwater quality due to the percolation of fertilizers and pesticides used in agriculture.

All of these driving forces have pressures associated such as groundwater abstractions for irrigation of crops, or touristic areas, water supply, wastewater treatment, among others. It should be noted that other pressures were identified but due to time constraints and/or lack of information, they were not accounted. They include point source contamination from highways, groundwater abstractions for industrial use, and contribution of illegal wells.

Methodology

The general methodology of this study consists of two main parts, the identification and quantification of the DPSIR parameters that affects the Campina de Faro aquifer, and the further development of an Excel tool that comprises these variables and allows to compare different scenarios for further evaluations like the sensitivity of the parameters defined in the first stage.

The domain of analysis comprises the physical space defined by the boundaries of the Campina de Faro aquifer system. The most important water fluxes across the boundaries need to be considered, namely the input of tap water and the export of (treated) wastewater. The assessment of impacts is made quantitatively by using appropriate emission factors to convert pressures (measurable quantities) into impacts (measured as tonnes of COeq) (eqs (1) and (2)). The model accounts for long-term natural driving forces, such as climate change, in the format of alternative modeling scenarios. The contribution of citizen science is introduced as way to help shape better more sustainable management alternatives.

Given the large uncertainty surrounding most of the variables and parameters, the outcomes of the model are themselves uncertain. The option was then to study uncertainty propagation through the model using Monte Carlo methods. This allows the quantification of the uncertainty of model results and the identification of most sensitive variables and parameters.

The independent variables measure pressures (P) in the environment for the different driving forces (L). Data consists of time-series for a period of ten years collected from public data repositories. Model parameters were obtained from literature or consultation of experts and stakeholders. They can represent: i) emission factors ($EF_{L,i}$) and forcing coefficients ($\alpha_{L,j}$), which quantify the causal relationships between variables; iii) or between societal responses and pressures or impacts ($\beta_{L,j}$) which are “target coefficients” in this study, as they are not known, but found in order to have a more sustainable management of the aquifer.

$$DF_L = \sum_{i=1}^{N} \tau_{L,i} \beta_i P_{L,i} EF_{L,i} \prod_{j}^{K} \alpha_{L,j} \quad (1)$$

$$DPSIR = \sum_{l=1}^{M} DF_l \tag{2}$$

The dependent variable is the DPSIR index, computed as the weighted sum of impacts per driving force. The weights $\tau_{L,i}$ can take value 1 when the impact is of positive signal, indicating an socio-economic or environmental benefit; or negative otherwise.

In order to study the uncertainty of the model, all quantities are input in the model as probabilistic distributions. When series of data were available, the parameters of a normal distribution were directly computed from it. If the time series showed trend, it was first linearly detrended before obtaining the statistical parameters.

When doing the Monte Carlo simulations, the estimates for these variables were obtained by the sum of the deterministic trend plus the stochastic obtained from the statistical distribution. Variables for which only a single value was available were modelled either using a one sigma assumption, i.e., with a normal distribution with standard deviation equal to the mean; or using a PERT distribution with two extremes and a most "probable" value.

Coefficients of the climate change scenario

Based on the simulations made during projects "Climate Change in Portugal: Scenarios, Impacts and Adaptation Measures": SIAM and SIAM II (Miranda, 2006), effective recharges are expected to decrease during the following years. We use here their projections for 2050.

The aspects that the project considered and are also contemplated in our future scenarios are the decrease of groundwater level, sea level rise, which will lead to a reduction of the thickness of freshwater lens in the aquifers and the decrease of precipitation itself. The decrease of groundwater level is input in the model as a forcing coefficient ($\alpha_{CC,\ gw\ level}$) that affects the water level in the aquifer, and thus forces to pump from deeper depths, which leads to higher emissions of GHG. The effect of sea level rise ($\alpha_{CC,\ slr}$) is subtracted directly from the base scenario water level, because it provokes saltwater intrusion, which lead to loss of freshwater, and thus, a decrease in the water table. As the past coefficient, this forces to pump from deeper depths, which leads to higher emissions of GHG. Finally, the effect of the reduced precipitation is input as forcing coefficient ($\alpha_{CC,\ rp}$) affecting the amount of rain that could be collected in rain harvesting structures.

For the Campina de Faro aquifer estimates that varied between -45% and -25%, with an intermediate probable value of -30% were computed for the effective recharge. These were the values assumed to affect the groundwater levels and used as the forcing coefficients for $\alpha_{CC,\ gw\ level}$. The SIAM project predicted for the year 2050 that there will be a sea level rise of 0.12 meters, which represents a potential reduction of 4.8 meters in the thickness of the freshwater lens ($\alpha_{CC,\ slr}$). Finally, it predicted a decrease of precipitation in the southern region of Portugal of -28% for the year 2050 which was the use value ($\alpha_{CC,\ rp}$) (Miranda, 2006).

Coefficients of the citizen science scenario

The creation of future scenarios involving citizen science was made by adding response coefficients (β_i) which act upon “Pressures” and “Impacts”. These coefficients reflect the strategic and operational options set out by operational plans, and by volunteer and consensual water management options taken by water users. For instance, the more informed and aware the stakeholder is about the need to manage water, less water is waisted, and lower will be the groundwater abstractions. Likewise, the higher the awareness concerning the sources of contamination to the aquifer, less chemicals are used and less will percolate to the aquifer.

These suppositions are subjective; however, they can be backed up by the “Behavioral economics principles” from the New Economics Foundation (NEF).

Moreover, the engagement with the project is assumed to be a weighted sum of the coefficients presented in Table 1. It is presumed that all of them contribute in the same percentage to the engagement with the project and that if those coefficients will boost, also it will the engagement with the project, so they are related directly proportional. This assumption is also backed by the mentioned behavioral economics principles.

Table 1 Target coefficients that can affect some of the pressures in future scenarios and their effects

Coefficient	**Notes**
Enhancement of “Pockock senses”	Refers to the guide "Choosing and Using Citizen Science" (Pocock, 2014). Includes: sense of jeopardy, sense of place, preexisting interest, being part of a narrative, sense of community and sense of discovery.
Incentives	Can be monetary, like reduction in taxes or so on.
Quantity of information in the app	Enrichment of the app with data provided by users for a more advantageous usage.
Instructions and teaching to community	Level of knowledge reached by the stakeholders during the project. For example, the hydrogeology of the Campina de Faro aquifer system.
Accompaniment to the community after the closure of projects	Monitoring and guidance to the participants after the implementation and closure of the projects.

Results and discussion

The running of the probabilistic model described in the previous sections for the current state of the Campina de Faro aquifer system, throwed the results presented in Table 2. Positive impacts were obtained from revenues from tourism and golf, nature conservation, and agricultural productions (avocado and oranges).

Table 2 Results of the DPSIR model in the three scenarios

Pressure	Impacts in tonCO2eq			% of variation	
	Base scenario (BS)	**Climate change scenario (CC)**	**Citizen science scenario (CS)**	**CC respect BS**	**CS respect BS**
Groundwater abstractions for irrigation of golf courses	-235.84	-385.1	-312.33	63.29%	32.43%
Groundwater abstractions for irrigation of touristic areas	-776.28	-1267.56	-1028.04	63.29%	32.43%
Water supply for tourists	-1553.38	-1685.25	-1685.25	8.49%	8.49%
Wastewater discharge from tourism	-347.98	-363.73	-363.73	4.53%	4.53%
Revenues from tourism	11115469.9	13338563.9	13338563.92	20.00%	20.00%
Revenues from golf	7220159.54	7220159.54	7220159.54	0.00%	0.00%
Regulations in Ria Formosa	61757.18	74108.62	74108.62	20.00%	20.00%
Point source pollution from airport	-714.66	-869.48	-869.48	21.66%	21.66%
Water supply for residents	-16482.9	-16482.9	-16482.9	0.00%	0.00%
Wastewater discharge from resident population	-3935.41	-3935.41	-3935.41	0.00%	0.00%
Infiltration of fertilizers and pesticides	-4310.88	-4310.88	-3483.02	0.00%	-19.20%
Groundwater abstractions for irrigation of oranges	-187.45	-400.44	-324.77	113.62%	73.26%
Groundwater abstractions for irrigation of avocado	-42.37	-126.04	-102.22	197.43%	141.23%
Production of oranges	215346.28	258415.53	258369.27	20.00%	19.98%
Production of avocado	272692.17	327230.6	327433.35	20.00%	20.07%
Total emissions related to “positive” impacts (revenues)	18885425.1	21218478.2	21218634.7	12.35%	12.35%
Total emissions related to “negative” impacts	-28 587.16	-29 826.79	-28587.16	4.34%	0.00%
DPSIR INDEX (Total emissions)	18856837.9	21188651.4	21190047.53	12.37%	12.37%

The water supply for the resident population is the pressure that causes the highest negative impact in terms of CO2 emissions. It is also the most important in terms of used amount of water, though the pressure is on water resources outside the aquifer – it must be accounted because otherwise the consumption would have to be guaranteed by the local resources (as it was in the past, when water supply was dependent exclusively on groundwater)

The groundwater use for the irrigation of crops of avocados, is the pressure that has the lowest of the negative impacts; however, it is not the pressure that uses the lowest volume of water, it is the wastewater treatment from touristic sector, which has more than triple of the emissions of CO2 eq.

This condition can be observed in all of the pressures related to groundwater pumping, which can involve larger volumes of water, but result in lower emissions of CO2 eq in contrast to the production of tap water, treatment of wastewater or groundwater remediation. This is because the groundwater abstractions only involves a pumping system generating emissions of GHG), whereas the water/wastewater/contaminated water treatment has a much longer life cycle emissions due to the several unit operations before distribution.

On the other hand, considering that in a 2050 horizon in the Campina de Faro aquifer system were climate change is imminent, the percolation of fertilizers and pesticides needs to be reduced almost 20% regarding to the present values. The groundwater abstractions for irrigation of touristic areas including golf courses need to be reduced to the point that the variation is half of what it would be in 2050 without the involvement of citizen science (32.34% vs 63.29%). The groundwater abstractions for the irrigation of oranges and avocados also needs a drastic reduction regarding the climate change scenario.

Finally, Figure 3 presents the weight of the pressures generating positive impacts, on the right it shows the base scenario results, and on the left it shows the future scenarios results.

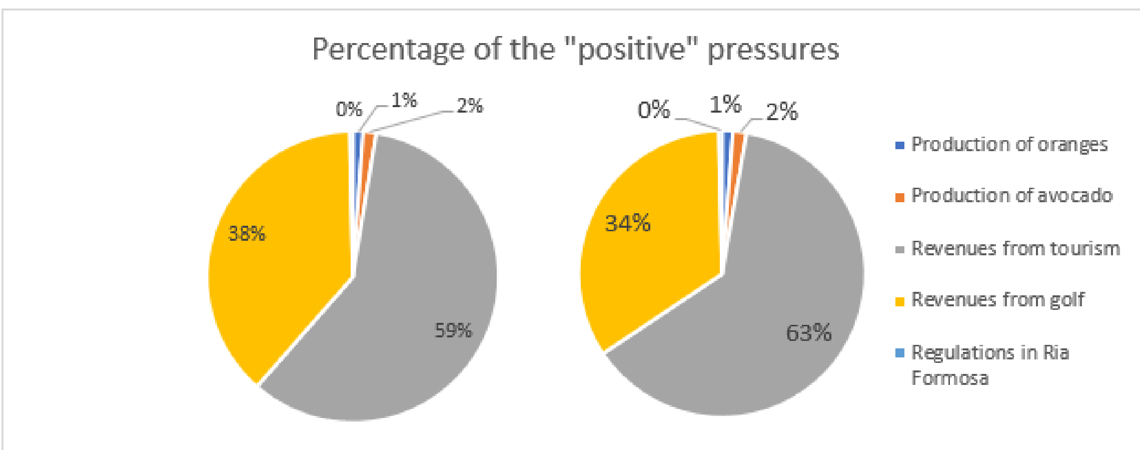

Figure 3 Weight of the pressures generating positive impacts in the base and future scenarios.

Only three pressures out of ten account for 87% of the total CO2eq emissions corresponding to pressures related to the water treatment: water supply for residents, water treatment of wastewater and treatment of polluted water due to the infiltration of fertilizers and pesticides.

Conclusions

The relationships between the different components of a DPSIR framework in the Campina de Faro aquifer system are:

- Drivers: tourism, resident population, agriculture, and climate change.
- Pressures: Groundwater abstractions for different purposes, water supply, water treatment (both because of contamination and wastewater), touristic activities, crop production, and sea level rise.
- State: Decrease in the groundwater quantity and quality, and revenues in the region.
- Impacts: Need of pumping from deeper depths and need of treating polluted water, thus more emissions of CO_2, and economic impacts.
- Responses: Citizen science and improve stakeholders' sensitivity to sustainable groundwater management.

Moreover, this investigation can be useful for the support of hydric resources planning and allocation in the Campina de Faro aquifer. Activities such as golf and touristic accommodations bring the region lots of revenues, and in terms of irrigation, use less water than the needed in agriculture. Besides, the first mentioned sector can use wastewater treated, whereas the farmers still look at this practice suspiciously. Thus, this should be considered when distributing water licenses for the different economic activities in the region.

On the other hand, the income from regulations in Ria Formosa should become mandatory, collected as a small amount needed to be paid by the visitors of the region whereas they go or not to the Ria itself. This, because as mentioned in the "results" section, the revenues from these regulations would cover all the total costs of emissions of CO_2 in the Campina de Faro aquifer.

Finally, regarding citizen science, the targets with the community of the Campina de Faro to keep the CO_2 emissions as the present ones are:

- An engagement of the community with the project during and after of 44%.
- An increase of 44% in the sensitivity of the participants for the seek of saving water and also the same amount for the seek of not polluting the aquifer.

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