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

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Thesis to obtain the Master of Science Degree in

Environmental Engineering

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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

Resumo

As iminentes alterações climáticas irão agravar os desafios relacionados com água em Portugal, especialmente no Algarve, como é o caso do aumento do nível médio das águas do mar, a diminuição na precipitação e mudança dos níveis de água subterrânea. Adicionalmente, práticas insustentáveis que têm vindo a ser observadas, tanto no sector turístico como no agrícola nesta zona sul do país, têm gerando graves problemas na qualidade e quantidade das águas subterrâneas do sistema aquífero da campina de Faro. Consequentemente, deverá procurar-se a melhorar forma de gerir o recurso na perspectiva do desenvolvimento sustentável. Este estudo apresenta um modelo dpsir como proposta para uma ferramenta de apoio à tomada de decisão participada para o aquífero Campina de Faro. Três cenários são modelados e comparados: um para o estado atual, e dois para condições futuras considerando alterações climáticas, com e sem uma gestão participada. As pressões exercidas no aquífero são avaliadas juntamente com seus impactos numa unidade de normalização (ton CO2 eq). Nos cenários futuros, são utilizados coeficientes que forçam o sistema no sentido pretendido. Incluem-se coeficientes para para simulação do efeito das alterações climáticas (por exemplo, redução da precipitação e da recarga efetiva dos aquíferos, e o aumento do nível médio das águas do mar). Outro conjunto de coeficientes força o sistema em sentido oposto, simulando as respostas da sociedade, em particular através de uma gestão participada. Mostra-se que no horizonte 2050, as emissões de CO2eq associadas às atividades desenvolvidas no aquífero (por exemplo, captação de água subterrânea para irrigação de áreas turísticas ou de culturas) irão aumentar em 12.3%. No entanto, também foi constatado que é possível manter o atual volume de emissões (28.59 mega ton CO2 eq), se se observar uma queda de 19 % na captação de água subterrânea, ou a sua substituição por outras origens, incluindo a água residual tratada, em todas as atividades da região, e também uma diminuição de 19 % nas concentrações de contaminates no aquífero freático. Essas reduções são alvos que a tese sugere e que se espera venham a acontecer com o aumento progressivo da participação de todas as partes interessadas no processo de gestão do sistema aquífero.

Palavras-chave: modelo DPSIR, ciência cidadã, gestão participada, gestão de águas subterrâneas, sistema aquífero de Campina de Faro

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1. Introduction

1. 1 Background and problem statement

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.

1.2 Research objectives

Main objective

To develop a quantitative DPSIR model in support to the eGroundwater project whose objective is to develop enhance information systems for the sake of boosting the understanding of some groundwater systems like the the Campina de Faro aquifer (which is the study area of the present research), aiming for a sustainable water resources management by using participatory monitoring.

Specific objectives

I. Find the main causal relationships between the natural and anthropogenic driving forces and the observed impacts on water quantity and quality in Campina de Faro aquifer system.

II. Evaluate the impacts of the climate change for a future scenario in the study region.

III. Define an objective in the involvement of stakeholders for the improvement of the groundwater quality and quantity.

Research questions

I. Which are the driver forces that exert pressure in the Campina de Faro aquifer?

II. What are the causal links of the drivers-pressures and the state-impacts of the study area?

III. How to set the level of participation and thus the information provided by users as different input scenarios in a DPSIR model?

1.3 Outline of the thesis

This document contains seven main chapters. Chapter 1 gives an insight of the motivation of the project and the current situation given the anthropogenic/climatic background of the study region. Then in the chapter 2, an overview of existent research of the approach that is applied in the thesis (DPSIR) is presented in order to make way for the chapter 3, which explains the methodology implemented. Then chapters 4 and 5 describe the study area and model inputs followed by the setup of the tool. Finally, the last two sections expose the results with the conclusions that they entail, hand in hand with suggestions to outlook for future work.

2. Literature review

The following section presents an overview of some research that have already been done in the topics of the thesis: first there are shown some studies regarding the type of model used in this investigation (DPSIR framework), then it is presented some of the involvement of citizens in science, and finally there are some examples in literature of how these two concepts have been joined (DPSIR and citizen science).

2.1 The evolution of DPSIR frameworks: strengths and weaknesses

Over the past two decades the DPSIR cause-effect method, conceived to evaluate environmental risks has been increasingly used by the scientist community. It has been recommended when assessing nature-related matters, e.g., by the Canadian Council of Ministers of the Environment (CCME, 2017), Organization for Economic Cooperation and Development (OECD), the European Environment Agency (EEA), and the European Council (namely in the Water Framework Directive, Directive 2000/60/EC. Figure 1 shows an example of conceptualization of the DPSIR in the water sector.

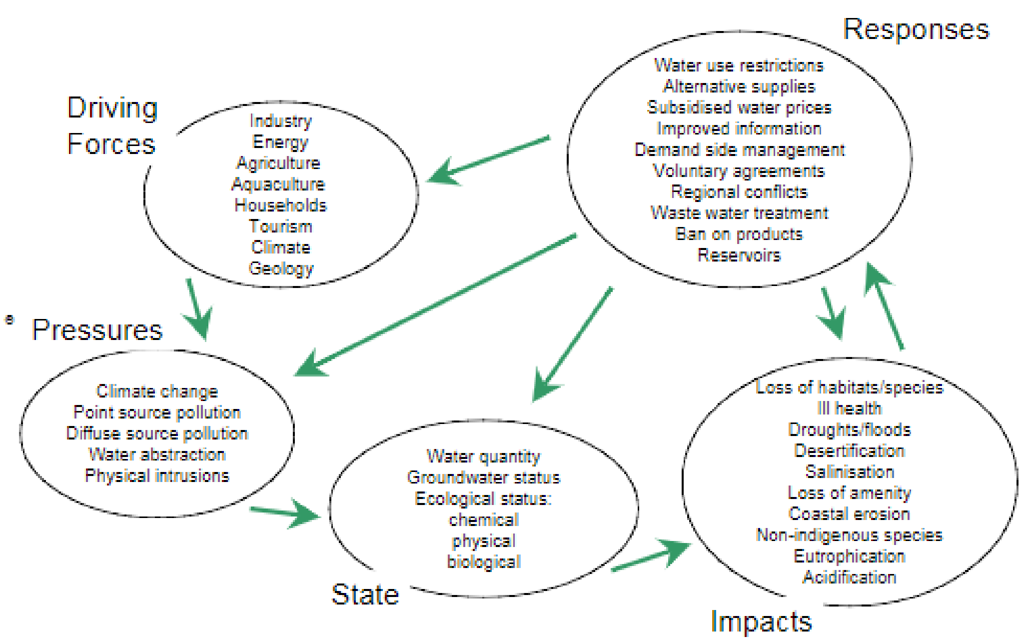

Figure 1 A generic DPSIR framework for water (Kristensen, 2004)

DPSIR is considered to be an efficient method for a first overall assessment of arising environmental issues, as it shows the linkage between the societal development produced by the human activities, which generates pressures, which, in turn, will modify the environmental conditions (Vannevel, 2018). For instance, “Driving forces” may be Agriculture, which exerts “Pressure” due to groundwater extraction for irrigation, leading to a “State”, which can be assessed by the hydraulic head. If the latter surpass sustainable levels, “Impacts” will arrive, “Responses” are ways of reducing or mitigating impacts by intervening in any of the components of the system — e.g., by limiting the issue of groundwater extraction licenses.

Even though the DPSIR framework has been extensively applied in many contexts, in the past years it has been receiving some criticism because of the complex systems it should cover: there are interdependences between the parameters, thus occasionally this method is not able to fulfill these interconnections.

Several solutions have been recommended to overcome the mentioned drawbacks. Mimidis K. *et al* (2017) suggested the use of sensitivity analysis, multi-criteria analysis, and visualization of digitalized data sets via GIS assisted software, if the objective is to compare different management alternatives. Kristensen P. *et al* (2004) stated it is not only important to study the linkages between the different elements of the DPSIR framework, but it is also necessary to study the relationships between parameters in order to fully understand the internal dynamics. For instance, a given “Response” proposed by a group of stakeholders to mitigate/reduce an “Impact” will be highly dependent on how the they perceive the impact and the causality chains. .

This latest concept was reinforced by El Sawah, S. *et al* (2011) when affirming that details in the connection of the different elements of the DPSIR chain are often missing. Nevertheless, these authors went even further by also questioning the lack of participation of stakeholders in the modelling process, which would help to clarify uncertainties, understand the roots of the problems, as well as the preferences and necessities of stakeholders. For this reason, a four-phase participatory modelling was by them suggested which includes: assess the context of the study area and the project needs (scoping), structure issues and define purposes (framing), modelling (including testing) and model use with which conclusions and decisions can be made.

Owing to the aforesaid, separate proposals deviations to the traditional DPSIR model have been made, adapting to specific circumstances of the individual contexts, accounting to 25 different schemes shown in Figure 2 that keep the essence of the conceptual models of systematizing, screening, and explaining the issues, but modify one or more parameters in the DPSIR approach (Patrício, Elliott, Mazik, Papadopoulou, & Smith, 2016).

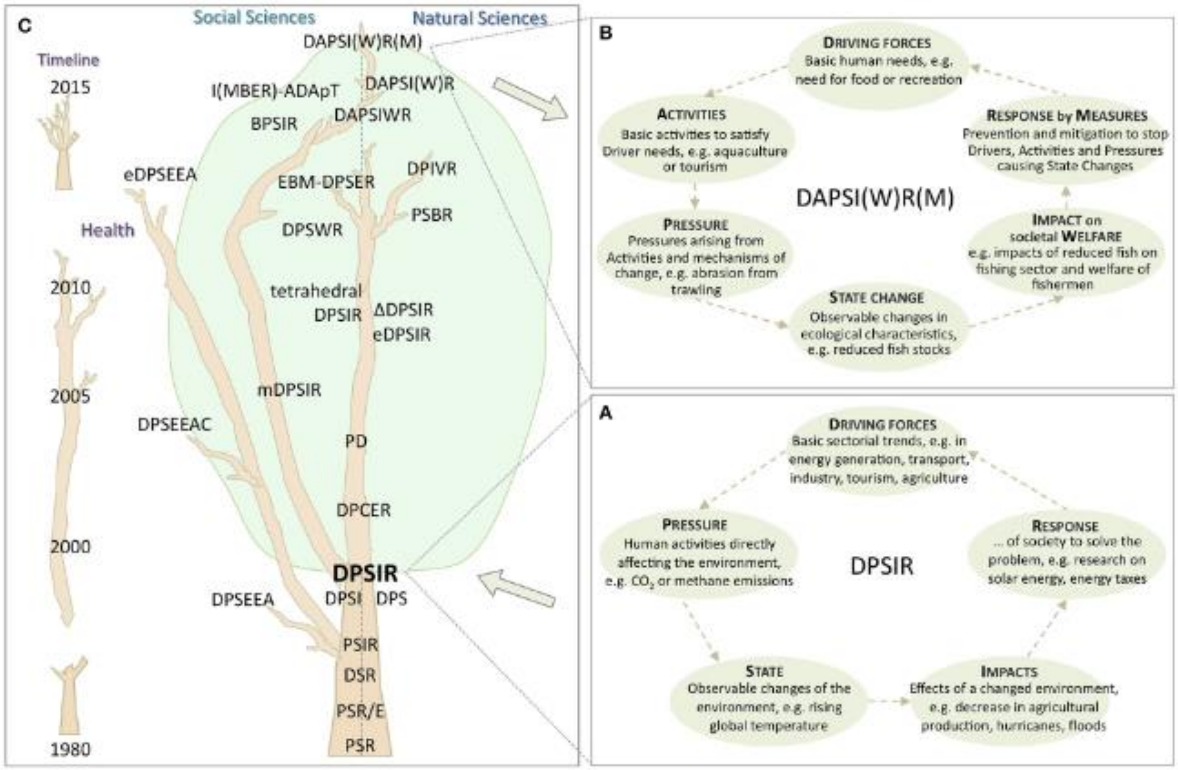

Figure 2 DPSIR and derivates development (A) DPSIR first elaboration, redrawn from the original EU framework (EC, 1999), (B)DAPSI(W)R(M), top of the tree evolution of DPSIR (as defined in Scharin et al., 2016), (C) timeline and development/relationship of DPSIR and derivatives. (Patrício, 2016)

For instance, in the "ResponSEAble project" a DAPSIWR Framework is proposed of the stewardship of marine environments, which adds the categories "Activities - A" and "Welfare – W" between D and P, and I and R respectively, because the first one is needed to carry out the driver's purposes defined as human necessities, and the second one considers the mankind welfare (assessed by means of ecosystem services state), leaving the parameter "Impacts" only to evaluate the environmental effects. (Brennan C. *et al*, 2019).

Moreover, framing the DPSIR approach inside a wider spectrum is also a suggestion contemplated in literature in order to cope with its weak points. Vannevel R (2018) proposed a Pentatope Model that included DPSIR framework along with the societal capitals, ecosystems governance and Environmental Information Cycle (EIC), which includes the monitoring, data management, reporting, knowledge, and Central and Intermediate Modules (i.e. IT tools). This model has the advantages that each sub framework has different strengthens and weakness to the other ones, thus ones will support the other ones filling gaps, for instance, EIC can provide information but DPSIR will be the one in charge of describing the effects due to the interaction between the Societal Capitals and the Ecosystems.

On another hand, the DPSIR is a very well-known and applied method in environmental management contexts. However, its use for groundwater management is new: only since 2006 has it been appearing in scientific journals and is now gaining momentum. Figure 3 produced in Web of Science shows the number of journal articles mentioning both “DPSIR” and “groundwater” from its first appearance until the present year (Nunes, 2021).

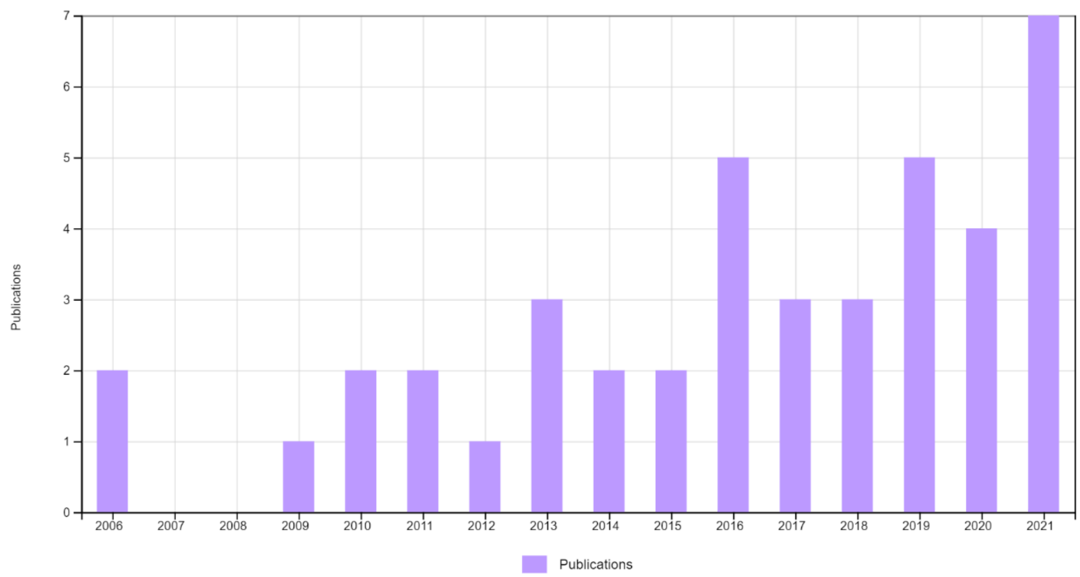

Figure 3 Number of journal articles that mention both "DPSIR" and "groundwater"

Summarizing, the DPSIR framework is a powerful tool, yet it can eventually oversimplify by omitting system dynamics and by assuming linear and unidirectional relationships. Thus, it can and has been improving over the years by being modified into a branched structure, nonlinear but cyclical, and with feedbacks between stages, so it can be applicable at different levels of governance (Vannevel, 2018).

2.2 The engagement of citizens in science

At the end of the XX century, the sociologist Alan Irwin, defined a novel concept: Citizen Science. He stated it was “a science which assists the needs and concerns of citizens” and “a form of science developed and enacted by the citizens themselves” (Dennis, 2019). Furthermore, it is the collaborative participation of people from a general ambit into scientific projects, by recording, monitoring and in some cases analyzing environmental data. Therefore, involving communities in the design of projects, collection of information, brainstorming for management plans, and in general a good implementation of citizen science, enhances the awareness of societies, as it can reduce gaps in scientific campaigns, improve resources, and thus, the most direct consequence is that the scientific community will have robust data to use and with that provide people with services such as enhanced information systems (Pocock, 2019).

Dennis, (2019) suggested six factors that determine a correct implementation, and thus the suitability and the success of a citizen science project. They are presented in Figure 4.

Figure 4 Factor of success in citizen science (Dennis, 2019)

Moreover, the manners of involving citizen scientist in projects can be categorized according to the level of engagement. For instance, Pocock (2019) separates it into two: a contributory and a collaborative approach. In the first,the professionals design activities (e.g. environmental monitoring) , being the one implemented most frequently; while in the second, the participants are engaged at a early stage, when defining the scope and methodology. Another example is the four levels of engagement division according to Hacklay (2013): crowdsourcing (volunteer computing only, not cognitive input), distributed intelligence (data gathering in processes designed by scientists), participatory science (collection of information and definition of the problem) and extreme citizen science (all together adding analysis).

In the past two decades, there have been many studies in water resources management involving citizen science, mainly regarding water quality, and in most of the cases limiting the role of the nonscientific individuals to monitoring and collecting data, but not doing the water quality testing (Baalbaki, 2019). However, if the duties of the citizens were expanded, the communities could be empowered to acquire skills needed to long-term studies. In addition, hitherto few studies include an accompaniment of the effects of the mitigation implementations, which could be covered as well if the roles of citizens is less restricted.

Likewise, citizen science is also a useful tool to boost the trustworthiness of a community in the policies of both governmental and private entities, as it was proved in the study carried out by Jamieson (2019) that evaluated the implementation of two programs by the Queensland, Australia Government in an area were coal seam gas developments have been increasing in the past decades, because the landholders had misgivings about the negative impacts resulting from these activities and the transparency of the information. The two projects are web-based aquifer monitoring, and the users have the possibility of submitting groundwater data directly from a computer or a smart phone.

The objectives of these programs have been accomplished so far as the monitoring volume did increase over the years, the confidence of communities in the companies and government information did improved as the data provided by citizens match the one provided by the first ones, and the understanding of the impacts did also upgrade. Something similar happened in the project carried out in Lebanon by Baalbaki (2019) who implemented a citizen science approach to assess the groundwater quality of a village, and the outcomes from both the community and the university experts were alike showing no significant differences in 7 out of 11 tests that were carried out. Thus, the trustworthiness of the participants improved, as well as their own knowledge in the topic, to the extent of creating a water committee in the village.

Nevertheless, the mentioned confidence must go both ways, this means that the citizen science can address the lack of trust of a community in information provided by authorized entities, but also the data collected should have a level of trustworthiness enough in order to be used by the scientific community. Studies show that when giving a proper instruction, guidance and motivation to citizens, the reliability of the data is high, however, it is noticeable that this training, leading and supervision requires large amounts of time and energy which should be considered (Manda*,* 2021).

Thus, resources availability, scale of sampling and complexity of protocols are some indicators of the suitability of a citizen science project (Dennis, 2019).

Furthermore, a final issue to be considered by researchers or authorities who rely on citizen scientist, is their engagement on the long run, given the volunteer nature of the participation. Thus, keeping stakeholders involved and updated on the relevance and advantages of their role in the program is critical, for example with the use of regular journals or web sites (Little, 2016).

An example of citizen science: eGroundwater

Based on the association of participatory methods (citizen science) with Information and Communication Technologies (ICTs), eGroundwater is a four year's project that seeks for a sustainable groundwater management in the Mediterranean region, in order to provide complementary data to the traditional methods in selected aquifers, among them the Campina de Faro aquifer. Collateral benefits would be the assessment of the potential socio-economic impacts when sharing this water body, considering interactions among stakeholders, way of usage and implementation of rules (eGroundwater, 2021).

Figure 5 Workflow of the eGroundwater project (eGroundwater, 2021)

Data provided by users will be pumping rates (per borehole or agricultural plot), groundwater levels (depth measurements at boreholes), and water quality (with portable kits). The latter two will be also collected by traditional methods from national authorities or associations, who will also provide the groundwater discharge values computed in an indirect way by measuring the discharge from stream flows in rivers who share known connections with the aquifer. In addition, with traditional systems the meteorological variables will be also recorded, and corroborated with earth observation technologies, which will also provide crop evapotranspiration and vegetation dynamics. Finally, with sensors four parameters will be evaluated and/or corroborated: soil moisture, evapotranspiration, groundwater levels and pumping rates (Pulido-Velasquez, 2020).

This interconnections between the data gathered by users and by traditional systems will act as a cross-validating method to make reliable the information provided by finding inconsistences, including the spatial variability. This double check technique has already been implemented in projects similar to eGroundwater, for instance the one developed by Dennis, (2019) which also developed in South Africa a groundwater mobile app engaging citizen scientists who were star-rated and thus, the reliability of the data provided by them was measured: a one-star user means that the trustworthiness of the data was low and needed to be verified by a user of higher rate. Once the one-star has several verifications, the rate increases.

Additionally, the accessibility to the outcomes that result thanks to the collaborative data acquirement, is also evaluated in the eGroundwater project as well as in other projects of this nature, like the exposed by Jamieson (2019) in Australia which immediately publish all available data online for all public access via Queensland Globe, or like the one mentioned above where the contributors are the only ones who can access to bulk downloads of data in order to stimulate them to keep participating and monitoring. In the case of eGroundwater some information will be accessible to general public through a public data repository (Zenodo) and to particular users, full access to all datasets will be given with an account if they are contributing with own measurements (Pulido-Velasquez, 2020).

Lastly, the eGroundwater project has identified issues for instance, the inconsistence of user engagement, fortunately, the likelihood of this to happen is considered low because previous interactions with stakeholders have already been done, however, a contingency plan is designed that includes workshops/trainings and continue communication trough calls and/or mails. These instructions will be also useful to cover the risk of limited users uptake of the platform due to lack of understanding because of different educational degrees, languages and background (Pulido-Velasquez, 2020).

Citizen Science impacts

It has been mentioned so far: the Citizen Science is a growing practice that has helped researchers to cover gaps and to have diverse insights, as well as it has improved the knowledge and capacities of participants before aliens to matters as decision-making, or projects' design for example. However, among the scientific community there is not an agreement (or it is diffuse), on how to measure the impacts or the actual changes that result from applying Citizen Science.

Some authors have assessed the outcomes from each own specific project reaching to numbers or qualitative levels, but those final evaluations cannot be extended to other areas of study, given the diverse nature of the practices. Whereas other authors have reviewed several studies to identify patterns, concluding that the evidence of the impacts of Citizen Science is normally not well documented. In fact, nowadays there are no standardized procedures to evaluate this (Wehn, 2021).

Therefore, efforts have been done in order to examinate the processes and actual changes that should emerge after community-based initiatives. For example, Gharesifard, 2019 devised a conceptual framework that evaluates the contexts, the processes and the impacts of Citizen Science projects, by assessing five dimensions that they assume are inherent to every study: Goals and objectives, power dynamics, technology, participation and results. They tested it two study cases with different background and knowledge area (Kenya: Sustainable livelihood and biodiversity management – Netherlands: Pluvial flooding), and although they function in almost opposite social, political, institutional and technological settings, the framework helped to evaluate them in a systematic and logical way that can be applied to any study.

Withal, a more recent example is the guideline proposed by When, 2021, where they wrapped up in six principles, the methodology that they think that an evaluation of citizen science outcomes should have, beginning with the acknowledging of the variety of purposes, passing by (among others) the contextualizing of the projects timings and backgrounds, and finishing with the cumulative enhacement of the framework over time. In all of the process of reviewing the 77 past studies, that led them to the suggested procedure, they considered five impact domains: Society, economy, environment, science & technology, and governance, and withal, they concluded that the large majority of researches don't cover all of them, and overall, excluding the science & technology, there are not a lot of quantitative methods to evaluate the domains.

Finally, the “Behavioral economics principles” from the New Economics Foundation (NEF) which based on the many observed traits coming from the fields of psychology, behavioral and experimental economy, presents a twist on the neoclassical analysis that presents humans as rational beings who behave in manners that allow them to maximize their self-interest, and instead it allocates principles to human conduct like that the people are motivated to ‘do the right thing’, that people are loss-averse, and that people need to feel involved and effective to make a change, among others (NEF, 2005).

2.3 Joining a DPSIR framework with Citizen Science

One type of engagement of the individuals in Citizen Science is the participatory modeling, which is a procedure that combines the engagement of the interested parts (users, decision-makers, suppliers, etc.) into an analytic model, transforming it into an integrated model to support management plans that seek to answer complex environmental questions and protect the resources, while taking into account the economic and social concerns of the community and not only the scientist (Voinov A., 2008).

There are several ways how stakeholders can be involved in the conceptualization and support of the DPSIR models . Thse include:

- Model construction by giving perspectives about causality chains, expectations of the outcomes and the different scenarios that can be used.
- Model construction by sharing their view and experience about how the system works.
- Model testing by questioning and/or validating the output with previous knowledge.
- Data collection by providing information that can further be used as inputs.
- In the case of decision makers, model.

For instance, Chung (2011) did a DPSIR model to support a Korean urban watershed management plan as the increase in precipitation in the area had exacerbated problems in the water quality and quantity. Later they asked the residents to rank the results of the model, so these stakeholders took part by validating the model. The authors got as responses seven alternative evaluation indices, which they divided into poor, acceptable and good. This way the preferences of the users were considered in the final process of decision-making.

Another example is a study of environmental degradation carried out in Ghana, where the participation of the community took place not only in the “Responses” part by proposing four different policies scenarios to the users, but also in the definition of “Pressures” by being key informants about legal and illegal mining, the quarrying and burning of scrub, and also by giving observations and by taking part in Geographical Information Systems analysis. Moreover, in this case it was concluded that with the DPSIR assessment the interrelations between indicators, community, modelers, and policy makers were facilitated and complexities of understanding the system were reduced (Agyemang, 2007).

Roura-Pascual (2009) also involved participants in more than one component of the DPSIR model created for the management of alien plant invasions by doing workshops at local scale in the Cape Floristic Region (CFR) in South Africa with a facilitator that compiled the information and stakeholders from all kind of backgrounds (from theoricians to field managers) followed by personal interviews. The participants helped in the identification of the components of the DPSIR framework, and the linkages between them. Moreover, the distinct biophysical and socio-environmental conditions inside three regions of CFR were recognized with the help of stakeholders, in order to seek for opportunities of a differentiated management plan. This led to the better understanding of the behavior of the plants and thus, a guideline could be proposed, for example with spatial prioritarization, budget and temporal context, among others.

Finally, in terms of monitoring the resources, and thus, the values that are input in a DPSIR model, a solution could be the “self-regulation” from users. An example from this is the project Piragua in Colombia, which is a water resource monitoring network based on a socio-environmental management scheme since 2011. It has created a culture of information with the communities and promotes and develops water information systems, built, implemented and operated by the users of 80 municipalities in a certain region. The project states that the information is the basis of governance and this in turn is the basis of the development of the participant communities, which are essential for the sustainability of the network. This data collection from participant communities can be considered as an input in a DPSIR model.

3. Methodology

The course of action of this research consists first in the identification and quantification of the DPSIR parameters that affect the study area (Campina de Faro aquifer) as well as the coefficients that act on those elements in future situations. Second there is a development of a model that comprises the mentioned variables, and that allows to compare a base scenario with two future ones: climate change as business as usual, and climate change with societal response supported by citizen science, both projected for the year 2050, accounting for long-term natural driving forces.

3.1 Identification of the DPSIR components

The definition of the DPSIR elements that are part of both the base scenario and the future scenarios, is based on consultation of experts and stakeholders, and mostly on literature on previous research about the implementation of this method in other aquifers (e.g. Pyrgaki*l,* 2020, Mimidis*,* 2017, El Sawah*,* 2011).

The gathering of information for the later quantifying of the selected variables is made from public data repositories: National System of Hydric Resources of Portugal (SNIRH); the water supply company of the region (Águas do Algarve), the internal help from people of the project eGroundwater, among others that can be seen in section 6 in Table 5. It must be stated that many assumptions can be made due to the lack of information, therefore additional tools like georeferenced images can be considered as well.

Later, in the DPSIR framework "Driving Forces" need to be associated to "Pressures" and "States", and these then need to be quantified as "Impacts". Unlike physically-based models, the state of the system is not always necessary to calculate the impact. The impacts in DPSIR are quantified as emissions contributing to global-warming, which require, in many cases, only the value of the pressure.

In the proposed DPSIR framework, the specific pressures-states-impacts that are associated to each of the above-described driving forces are presented in Table 1.

Table 1 Relationship the different driving forces, pressures, states, and impacts

Drivers	Pressure	State	Impact (DPSIR)
Tourism	Groundwater abstractions for the irrigation of the golf courses	Decrease of water table in the aquifer	Need to pump deeper→More energy →More €
	Groundwater abstraction for irrigation of other touristic areas	Decrease of water table in the aquifer	Need to pump deeper→More energy →More €
	Water supply for tourists	Destabilization of the water balance of the basin	Need to look for another water sources i.e. Campina de Faro aquifer
	Wastewater discharge from tourism	Alteration of groundwater quality	Cost to treat wastewater
	Point source pollution from airport	Alteration of groundwater quality	Remediation costs
	Golf and other touristic activities	Development of the region	Revenues
	Nature conservation and value	Preservation of the ecosystem	Non-economic values: willingness to pay
Urban areas	Water supply for residents	Destabilization of the water balance	Need to look for another water sources i.e. Campina de Faro aquifer
	Wastewater discharge	Alteration of groundwater quality	Cost to treat wastewater
Agriculture	Percolation of fertilizers and pesticides	Alteration of groundwater quality	Cost to treat polluted water
	Groundwater abstractions for irrigation	Decrease of water table in the aquifer	Need to pump deeper→More energy →More €
	Production of oranges and avocados	Development of the region	Revenues

3.2 Implementation of the model

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 an objective 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 ($\alpha_{L,j}$) (Table 2), 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 (Table 3).

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

$$DPSIR = \sum_{l=1}^{M} DF_l \quad (2)$$

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.

Regarding the value of constants (model coefficients), the literature also used in the development of the future scenarios for quantifying the so called "forcing coefficients" which are related with the climate variation. However, in the case of citizen science the procedure needs to be different because it depends on the engagement of the community. Therefore, the approach in this study is objective oriented, which means that a quantitative target is established, and from there, the value of the coefficients are sought to reach that goal.

Table 2 Forcing coefficients that can affect some of the pressures in future scenarios and their effects.

Forcing coefficient ($\alpha_{L,i}$)	**Effect**
Prediction of rise of sea level	If the sea level rises, there will be saltwater intrusion, which would lead to loss of freshwater in a 1:40 ratio according to the Ghyben-Herzberg relation. If there freshwater lens decreases in the aquifer, so it will the water table and there will be a need to pump from deeper depths
Prediction of recharge decrease	If the recharge decrease, so it will the water table and there will be a need to pump from deeper depths
Prediction of precipitation decrease	If there is less precipitation, there will be less water to be collected and used by rain harvesting
Percentage of affected groundwater with fertilizers	Groundwater quality is affected by the nitrates that percolate due to agricultural practices, and thus there is a need to remediate in order to be able to use the groundwater
Efficiency of pump system	With a higher efficiency on a pumping system less CO2 emissions will be, and opposite.

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) exposed in section 1.

The assumptions for setting the response coefficients were:

- Willingness of stakeholders to act is moderated by fairness in a directly proportional way → If they believe that the efforts are proportionally distributed in a fair way, they will be more willing to act.

- Stakeholders will hold on to their belongings even under the cost of a higher risk → If stakeholders consider the aquifer as “theirs” they will find ways to avoid losses related to it, even with larger risks (i.e., using less water in agriculture)
- When stakeholders feel that they have some the control, they will feel motivated to improve things → If stakeholders feel that their actions will make a positive impact in the aquifer, they will be motivated to abstract less groundwater.

Moreover, the engagement with the project is assumed to be a weighted sum of the coefficients presented in Table 3. 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 3 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.

An example to elucidate the exposed above can be as following, for the base scenario:

Pressure (P): Groundwater abstractions for irrigation of golf courses 3.25 hm^3 (APA, 2019) at the actual water level depth 12.43 m (SNIRH, 2021)

Emission Factor (EF): Energy 2725 $kWh/(hm^3*m)$) (National Centre for Engineering in Agriculture, 2015)

Forcing coefficients (αl,i): Sea level rise, water level decrease (0 m, 0 m). Because it is the base scenario without climate change.

Citizen science coefficients (β): Spare of water, engagement with the project (0%). Because it is the base scenario without citizen science.

$$Impact = 3.25\ hm^3 * (12.43\ m\ + 0\ m\ + 0\ m) * (2725 \frac{kWh}{hm^3 * m})$$

Moreover, as stated above, 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.

For instance, in the exposed example, the value of 3.25 hm^3 was a single value of 2019 obtained from the Regional Hydrographic Management Plan of the Portuguese Environmental Agency, therefore it was input in the model using a one sigma assumption. This means that both the average and the standard deviation were 3.25.

Once the model is set up, it can be run for the different scenarios: base and future, assuming or not the contribution of citizen science. The impacts can be grouped according to their kind (socio-economic, environmental) in order to better understand how each driving force and pressure affect the value of the index.

4. Case study

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).

It 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) .

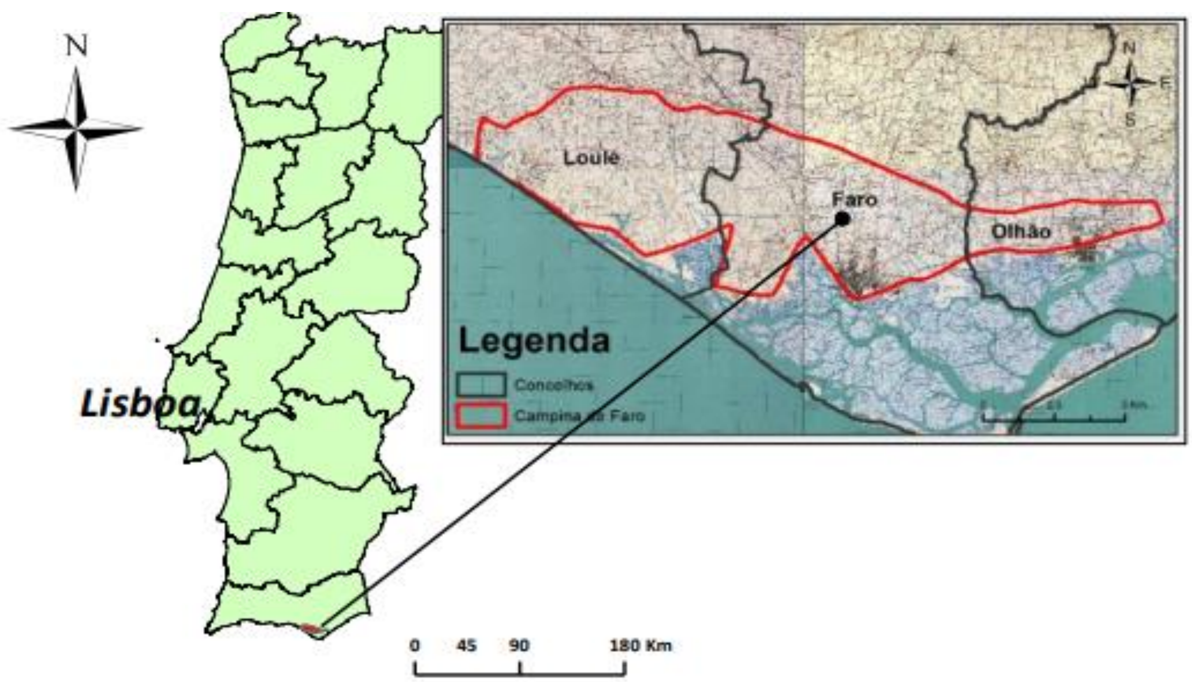

Figure 6 Location and delimitation of the Campina de Faro Aquifer. (Viegas, 2015)

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.

The National Water Plan in 2002 (Plano Nacional da Água - PNA after its Portuguese acronym) reviewed and updated the last time in 2015, establishes the need to provide an integral approach, supervision and operation for water resources, by aiming at three main objectives: the classification and protection of the dependent ecosystems, the encouragement of the sustainable and balanced use of water considering long term projections, and the increase of the resilience against extreme events like floods and droughts, every time more recurrent due to both the natural large climate variability of Mediterranean areas, as well as due to climate change (APA, 2015).

For the purposes of water management, the PNA divided Portugal in ten hydrographic regions (RH), for which specific water management plans were developed (PGRH), which considered both the surface water bodies and groundwater. The Campina de Faro aquifer system is located in the RH 8 which belongs to the hydrographic basin of Ribeiras do Algarve. The specific targets of the PGRH regarding the groundwater resources are to limit the discharges of pollutant substances into the subsoil, as well as revert any actual tendency that keeps their concentration growing, and to maintain or reach a good state both in the chemical aspect and the quantitative aspect of the aquifers (pumping-recharge equilibrium). These goals were defined into cycles of 6 years respectively: 2009-2015, 2015-2021 and 2021-2027 Each of them, follow a procedure of characterization, classification, monitorization and implementation of policies, as well as in the involvement of the interested community in some stages through partaking resources like divulgation of information, explanatory sessions, or contributions of stakeholders in websites (APA, 2021).

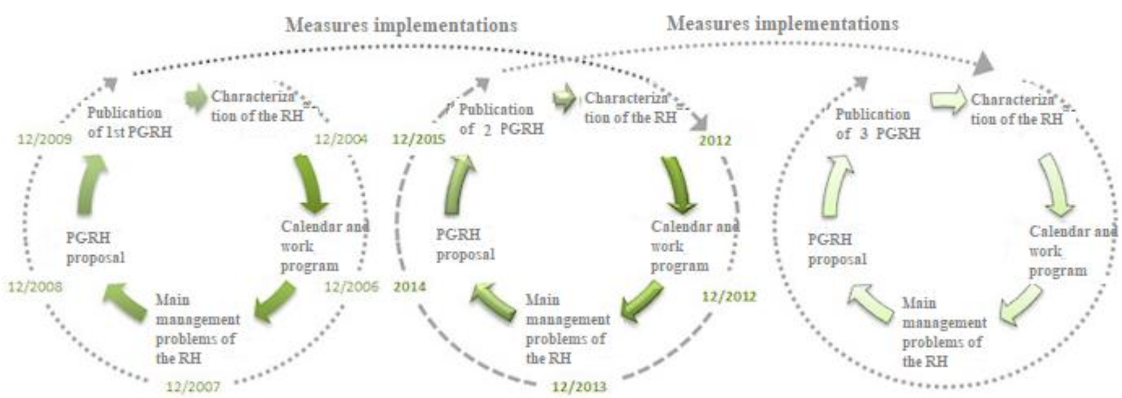

Figure 7 Framework and linkage of the three cycles for the Plan of Management of Hydrographic Regions (PGRH) (APA, 2021).

In the middle of the period of the first cycle (2012) a report was delivered, which characterized the different pressures that the water bodies were subject to. Regarding Campina de Faro, qualitative pressures, both point and diffuse, were identified, this latest due to the use of fertilizers in agriculture, which led to an increase in the concentration of nitrates and with that the aquifer started being under surveillance and control under the EU Directive 91/676/CEE, 12/12/1991, as a "nitrate vulnerable zone" accompanied by plans of actions, the most recent one update in 2010 under the "Portaria 83/2010, 10/02/2010" (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas, 2010).

Moreover, it wasn't the only water body in that time that presented this kind of pollution which decreases the water quality, thus in other aquifers of the region the use of the groundwater was disabled until later the "Good State" in quality terms was recovered. However, in the Campina de Faro aquifer system there was still water extraction, and thus a tendency of decrease in the piezometric level which led to a quantitative pressure. Furthermore, this aquifer became the only one in the Algarve region which had an unbalance between the recharge and the extractions with an approximate of water extraction of 145% of the annual mean recharge (APA, 2012). These conditions led the Campina de Faro aquifer to be classified as in "Mediocre State" in the first PGRH assessment and to have the target to change this classification by 2027 to "Good State" (APA, 2012).

Nevertheless, it must be stated that this unbalance was uncertain when the first cycle report was released, and it is still nowadays. The account of 145% of overexploitation was based in a water balance made in 2012 that considered inflows as known direct natural recharge coming from precipitation and uncertain indirect recharge due to the transfer of water in the deepest layers of the aquifer from the neighboring groundwater bodies to the north. Additionally, the considered outflows were known 440 boreholes and 243 combined boreholes + wells, along with an extra estimated water consumption to account for unknown sources (APA, 2012).

In 2016 a report for the second cycle was released, which is the one in force today. It divided the Campina de Faro aquifer 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).

On the other hand, 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).

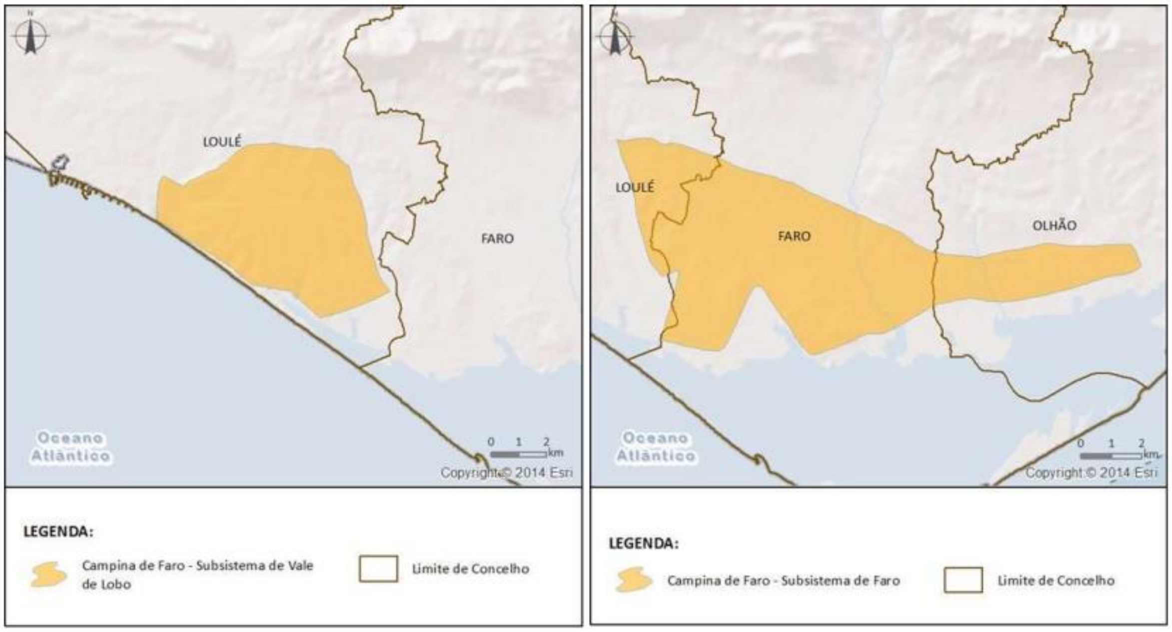

Figure 8 Campina de Faro water management subsystems of Vale de Lobo, on the left, and Faro, on the right (APA, 2016).

Summing up, since both subsystems are not in a "good" state globally (quality and quantity), the whole Campina de Faro aquifer is still labeled as "mediocre" in the second cycle report of the PGRH. Thus, there was not an improvement regarding the first cycle and the target of being in a "good" state by 2027 remained stated in the report. It must be explained that this "long term" goal is due to the difficulty of eliminating the diffuse pollution of nitrates as it is a gradual process, thus the recovery of the quality of the groundwater body is slow even considering the policies and measures. (APA, 2016).

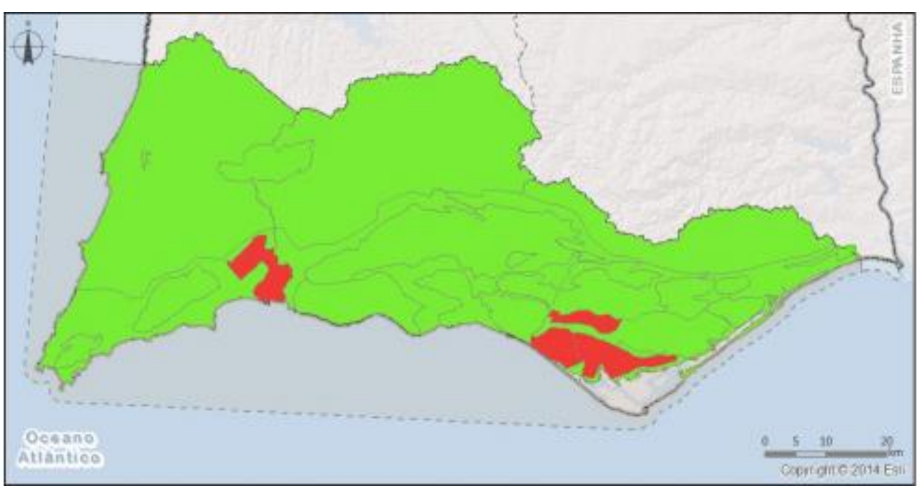

Figure 9 State of the groundwater bodies of the RH8. Green represents "Good State" and red "Mediocre State" (APA, 2016).

Finally, the third cycle was under public consultation until June 2021, for the subsequent publication of results at the end of the 2021. In December 2019 a partial report of significant issues of the water management was released and it didn´t show an encouraging outlook with respect the Campina de Faro aquifer state improvement, as the groundwater body is still in a quantitative "Mediocre State" with the piezometric levels in 2019 lower than the percentile 20, which led to the temporary suspension of new licenses for water extraction (APA, 2019).

Also a descriptive memory was released in July of 2020 with the basis of the PGRH for the RH8, based on it the Table 4 was made, which updated the information of 2016 about the groundwater balance of the two subsystems, and the water availability in Campina de Faro subsystems is critic at the end of the hydrological year.

Table 4 Groundwater availability and uses considering a long-term annual recharge (60 years) and satisfying identified needs (APA, 2020).

Subsytem	**Vale do Lobo**	**Faro**
Outflow (Extractions + 10%) in hm^3	6.452	5.315
Water used in agriculture 2019/20, in hm^3	2.421	5.203
Water extraction for golf fields in 2019/20 in hm^3	3.251	-
Inflow (Long term mean annual recharge) in	3.46	5.7
Available groundwater resources in hm^3	3.11	5.13
Available water at the end of the hydrological year 2019/2020 (Available groundwater resources - Outflow) in hm^3	-3.34	-0.19
Available water volume for extraction in the hydrological years 2019/2020 and 2020/2021 in hm^3	0	0

Finally, the groundwater quality/quantity problems in the Algarve is centuries-old, and several "Responses" have been considered by the water authorities of the region such as the catchment from the river Guadiana, the reuse of waste water, the construction of reservoirs, and the desalinization of water among others (APA, 2020). In this study, the proposed response is the DPSIR itself which intends to be a support for a more sustainable management of the aquifer.

4.1 Base scenario

The current state of the Campina de Faro aquifer is the result of the accumulated pressures exerted over time. Due to data limitations the base scenario was built with data for the period 2009-2019. Given that almost each parameter's value was retrieved from a different source, Table 5 presents a summary of the data applied for the base scenario and where did they come from.

Table 5 Average value and standard deviation of each pressure used in the base scenario

Pressure	Mean	σ	Unit	Source
Groundwater abstractions for irrigation of golf courses	3.25	3.25	hm^3	APA
Groundwater abstractions for irrigation of touristic areas	10.7	10.7	hm^3	Computed [1]
Water supply for tourists	1.22	1.99	hm^3	Computed [2]
Wastewater discharge from tourism	0.91	1.37	hm^3	Computed [3]
Tourists present in the area	1073573	20655	Number of tourists	Pordata
Economic activity in golf courses	1378000	53847	Number of rounds	Associação Turismo do Algarve [4]
Willingness to pay in Ria Formosa	1073573	20655	Number of tourists	Pordata
Point source pollution from airport	9010860	437170	Number of passengers	Pordata
Water supply for residents	22.51	1.99	hm^3	Pordata
Wastewater discharge from resident population	16.96	1.37	hm^3	Águas do Algarve
Percolation of fertilizers and pesticides	4.58	4.58	hm^3	Computed [5]
Groundwater abstractions for irrigation of oranges	4.1	4.1	hm^3	Computed [6]
Groundwater abstractions for irrigation of avocado	1.75931	1.75	hm^3	Computed [7]
Production of oranges	931	931	ha	DGT [8]
Production of avocados	269	269	ha	AGRO.GES

"Impacts" are quantified after multiplying the value of the pressure by the emission factor ($EF_{I,i}$). This converts all units to tonCO2 eq. The emission factors are shown in Table 6.

[1] Assumed considering same amount of abstractions per ha as in the golf courses. Supported by remote sense data
[2] Assumed considering equivalent amount of water supply per tourist as for the residents.
3 Assumed considering equivalent amount of water discharge per tourist as the residents.
4 Additional sources like newspapers were used for the remaining years (2009-2019)
5 Assumed as a variable percentage of the annual recharge from APA (9.16 hm3)
6 Computed according to the water needs of cultivated oranges (4401 m3/(ha*year)) and the ha
7 Computed according to the water needs of cultivated avocados (6500 m3/(ha*year)) and the ha
8 Value double checked with the INE agricultural census from 2019

Table 6 Emission factors used in the calculations

Impact	Emission factor	Value	Unit	Source
Emission due to groundwater abstractions for irrigation of golf courses, touristic areas, and crops	Energy for pump one hm3 per m of depth	2725	kWh	Computed [9]
	ton CO2eq/MWh	0.75	ton CO2eq	SEAP Guideline Annex
Cost for treating water for water supply, as well as treating the contaminated water because of the point source pollution from airport, and the infiltration of fertilizers and pesticides	ton CO2 eq/hm3	731	ton CO2eq	Zubelzu & Álvarez, 2015
Cost for treating the wastewater discharge	ton CO2 eq/hm3	232	ton CO2eq	Zubelzu & Álvarez, 2015
Revenues from tourism besides golf	Euros per tourist	257.38	€	Turismo do Algarve
Revenues from golf courses	Euros per round	130.25	€	Computed [10]
Revenues from the regulations in Ria Formosa	Euros per tourist	1.43	€	Perna, F., 2001
Revenues from the production of oranges	Euros/kilo x kilo/ha	5750	€	Jornal do Algarve
Revenues from the production of avocados	Euros/kilo x kilo/ha	25200	€	AGRO.GES

This process follows equation (1) presented in the methodology section and requires either emission factors to convert pressures, for example from an abstracted volume into energy values, and thus, ton CO2 eq; or pricing factors to convert the rest of the pressures, for example from area of plantation to tons produced, and thus, euros

The resulting values in ton CO2 eq and in euros can be related one to the other by the cost of a CO2eq emission license under the EU Emission Trading System (ETS). The cost has fluctuated during the years, so the option was to compute the statistics for the normal distribution (1.86± 6.5 €/tonCO2eq. Anyway, all results will be shown in euros, even though the DPSIR is not an economic evaluation. The unit in which the index is measured is not important: one should look at the relative

[9] Assuming no energy losses, considering that 1 kiloWatt-hour (kWh) of electricity contains 3.6 MegaJoules (MJ) of energy, and that 9.81 MegaJoules are needed to lift up one meter one MegaLiter of water.
[10] Computed from the prices of the passes of 18 holes from different golf resorts of the region such as Quinta do Lago, Vila Sol, Vale do Lobo, among others

differences: i) between impact indicators in the same scenario; and between alternative scenarios and the base.

Some of the impacts have positive signal meaning that they contribute to increase the value of the index, for example the revenues from the tourism or the crop production; whereas others will have a negative effect on the index, which is the case of the costs of treating water and wastewater. Model runs were made in Excel using Oracle's Chrystal Ball add in for the uncertainty analysis.

4.2 Climate change scenarios

In this study the effect of climate change will be included by considering sea level rise, the decrease of precipitation, and thus, the drop of the effective recharge to the aquifers. These extra parameters will be considered in the model in the form of forcing coefficients ($\alpha_{l,i}$) that affect existing pressures (see Table 1). For example, the reduction of the recharge will be associated to the groundwater abstractions as with lower infiltrations rates, the water table will be deeper, and thus the pumping of water will be more costly.

Moreover, the already existent pressures will vary as well, because of the projections, for example no increase of resident population is expected, opposite to tourism that is estimated to continue growing. Details about the values of the forcing coefficients are provided in the following paragraphs.

Coefficients

In the year 2020, Portugal was classified as very hot and dry in relation to the period from 1931-2020. Additionally, anomalies in high mean annual temperature have been recorded since 1942 and started to be often since 1994 and yearly since 2010, making the past decade the hottest in all the Portuguese history since there are recordings of data. Something similar has occurred with the precipitation: the decade of 2011-2020 was the second driest following the decade of 2001-2010, with only 5 mm more of precipitation (IPMA, 2021). Figure 10 shows two examples of this phenomenon, because it summarizes the percentage of precipitation of the hydrological years of 2018/2019 and 2019/2020 in relation with the period of 1971-2000, and in the first case all the country had less than 100% of precipitation compared with the mentioned period and in the second case at least half of the country had less than 100%, which means dry and in some regions very dry, such as the area where the Campina de Faro is located as it can be seen in both hydrological years.

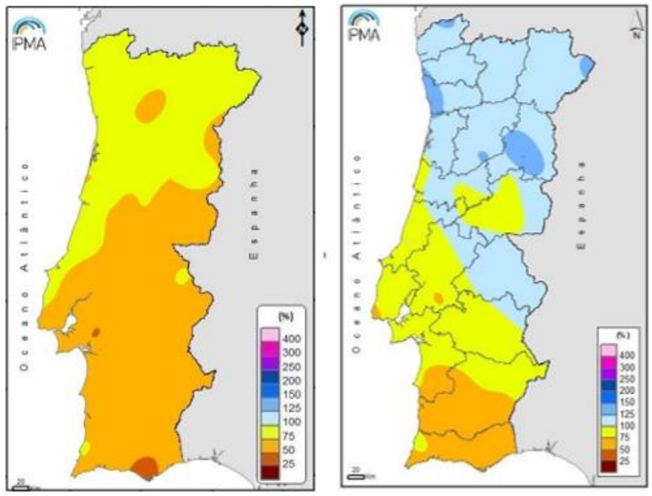

Figure 10 Percentage of total precipitation for the hydrological years of 2018/2019 (left) and 2019/2020 (right) in relation with the period of 1971-2000 (IPMA, 2020)

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.

Project SIAM contemplated two scenarios based on the atmospheric model HadCM3, one is more pessimistic (A2c) and the other one is more optimistic (B2a). Figure 11 presents these predictions of recharge alterations in the different basins of Portugal, according to both scenarios of the mentioned model for the 2050 horizon. However, for the present study the most pessimistic scenario was the one considered because the project SIAM was made in 2006, and the past decade showed only a decrease on the recharge. 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 $\alpha_{CC,\ gw\ level}$.

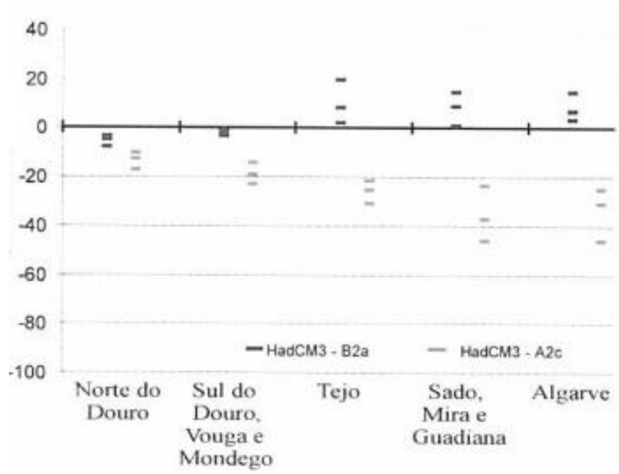

Figure 11 Predicted variation in the mean annual effective groundwater recharge for the horizon of 2050 in different basins (Miranda, 2006)

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 (Miranda, 2006) ($\alpha_{CC,\ slr}$).

Additionally, the predictions regarding the mean annual alterations of precipitation in relation to the period of 1960-1994 varied depending on the climatic model used, but to be coherent with the past values chosen, the most pessimistic scenario was chosen (HadCM3-A2c), which predicted a decrease of precipitation in the southern region of Portugal of -28% for the year 2050. (Miranda, 2006) ($\alpha_{CC,\ rp}$).

Pressures

The resident population for future scenarios was maintained equal to the base because according to the National Statistic Institute (INE in Portuguese) it is expected that the Portuguese population will decrease by 2080, but that the residents in Algarve may rise (INE, 2020). Thus, since it is a very blurred data, this pressure was defined to remain the same. The total area of golf courses was also considered to remain the same given the already high water demand from this use.

A rise of 20% in both number of tourists and agriculture area was considered. This means that it was assumed that the crop areas of avocados and orange were going to be 20% larger and that the number of tourists and airplane passengers were going to increase also in this amount. For making this assumption two official Portuguese reports were considered: the agricultural census (INE, 2020) and the touristic strategy plan for Algarve (TdP, 2014).

Citrus plantation area in the Algarve saw an increase of 21% in the period of 2009-2019; while avocado plantation area grew more than 600% in the same period (INE, 2019). This grow is not expected to continue because among others, these cultures were a novelty in the past decade, and is rather more probable that now that they are stablished, they continue expanding in a pace more similar to the crops that were already settled in the region. Therefore, a same rate of growth was chosen for both (20%).

The rate of increase of irrigated areas in the period 2019-2050 was assumed to be equal to that of the period 2009-2019, equal to 20%, because in the Portuguese Regional Plan of Hydric Efficiency of 2020 it is established that one of the administrative measures that will be implemented to increase water use sustainability is the revision of the emission of licenses of use of water resources. Thus, if getting licenses in the future was going to be more difficult, then the crop areas were not going to grow in such an accelerated pace.

The tourism strategy (TdP, 2014) estimated a rate of growth of 2.5% in four years (2015-2018), so the total increase for the future scenario 2050 would be $\left(\frac{0.025}{4}\right)^{(2050-2019)} = 1.21$. Thus a growth rate of 21% is used for the tourism in the horizon of 2050.

4.3 Citizen Science scenario

EGroundwater is a project that seeks to improve the understanding on the Campina de Faro aquifer system and with that empower a more sustainable governance of it, by using new opportunities of data gathering as is the community's participation.

The participation of stakeholders in the different steps of decision making related to groundwater management can help to support the development of the DPSIR model by providing their view of the relevant DPSIR components: driving forces, pressures, state and impacts; the causal relationships; external forcing; and societal responses. With the exception of the latter, the selection of all the other components are already the result of expert knowledge and stakeholder contributions during the many public consultations for the strategic water management plans in the region. Stakeholders haven't, however, stated yet their perspective and willingness to actively contribute to a participated management. As so, we opted now to search for sets of optimal response solutions which depend on citizen science.

Regarding the coefficients, instead of setting arbitrary responses, the option was to search for the best set of response coefficients that can guarantee a value of the DPSIR index in 2050 equal to that of the base solution (2019).

Even though the quantitative value of the response coefficient may be difficult to interpret and convert directly into actions, their relative weight will point out which response solutions may prove more efficient.

5. Results

This section presents both the results of each DPSIR scenario that was modelled: base scenario, climate change scenario with a 2050 horizon, and citizen science scenario also with a 2050 horizon. The DPSIR index is analyzed in units of CO_2 eq.

5.1 Base scenario

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 7. Positive impacts were obtained from revenues from tourism and golf, nature conservation, and agricultural productions (avocado and oranges).

Table 7 DPSIR results for the base scenario

Pressure	Impact in tonCO2eq
Groundwater abstractions for irrigation of golf courses	-235.84
Groundwater abstractions for irrigation of touristic areas	-776.28
Water supply for tourists	-1553.38
Wastewater discharge from tourism	-347.98
Revenues from tourism	11115469.94
Revenues from golf	7220159.54
Regulations in Ria Formosa	61757.18
Point source pollution from airport	-714.66
Water supply for residents	-16482.90
Wastewater discharge from resident population	-3935.41
Infiltration of fertilizers and pesticides	-4310.88
Groundwater abstractions for irrigation of oranges	-187.45
Groundwater abstractions for irrigation of avocado	-42.37
Production of oranges	215346.28
Production of avocado	272692.17
Total emissions related to "positive" impacts (revenues)	18 885 425.1
Total emissions related to "negative" impacts	-28 587.16
DPSIR INDEX (Total emissions)	18 856 837.94

The water supply for the resident population is the pressure that causes the highest negative impact in terms of CO_2 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 the double 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.

A clear example is the comparison between the treatment of groundwater polluted by the infiltration of fertilizers and pesticides, and the groundwater abstraction for the irrigation of touristic areas: these two pressures involve a very similar amount of water (11.79 hm^3 and 13.77 hm^3 respectively), but the first one produces more than 5 times the emissions of CO2eq than the latter.

The aforementioned situations are due to the processes involved in the two main categories of pressures considered: groundwater abstractions and water/wastewater treatment. This is because the former only involves a pumping system generating emissions of GHG), whereas the latter has a much longer life cycle emissions due to the several unit operations before distribution.

Figure 12 and Figure 13 show the relative weight of each negative impact, and the weight of each positive impact.

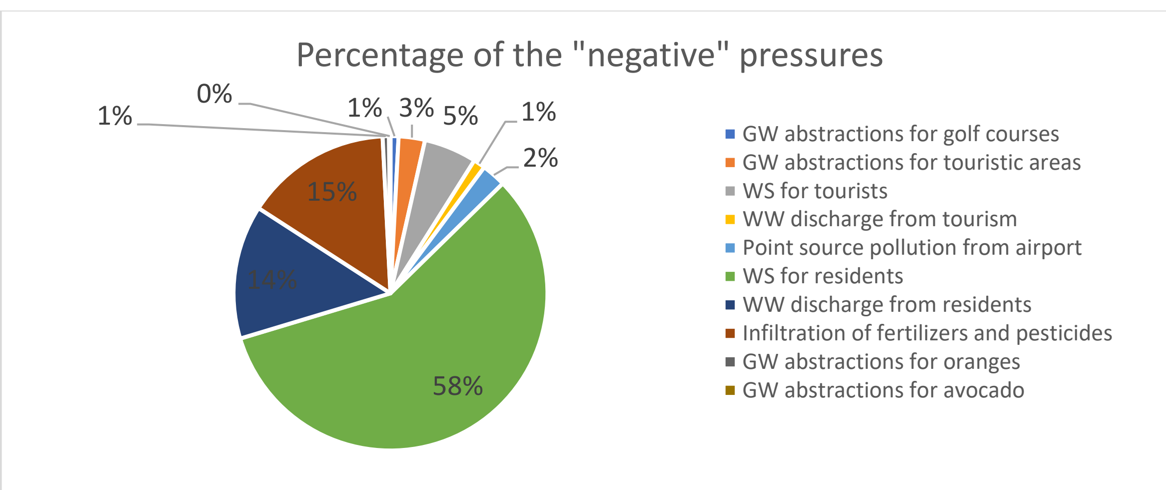

Figure 12 Weight of the pressures generating negative impacts

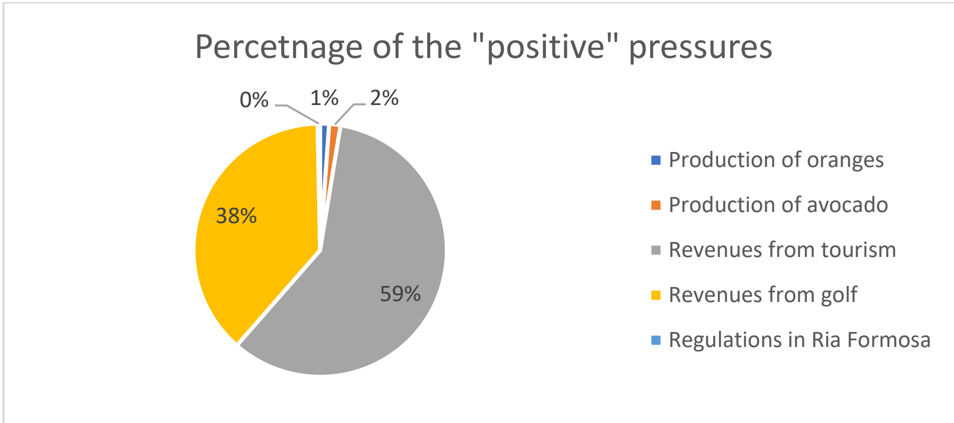

Figure 13 Weight of the pressures generating positive impacts

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.

On the other hand, in terms of positive impacts, it can be observed that almost all of them come from the touristic sector but it uses almost three times the amount of water than the production of avocados and oranges: 17.96 hm^3 from groundwater abstractions for irrigating golf courses and touristic areas vs. 5.85 hm^3 from groundwater abstractions for irrigating the mentioned crops.

Although the positive impacts from nature conservation are irrelevant when compared to the other pressures, they account for 61 757.18 tonCO2eq, which is almost double of the total emissions of the negative impacts, as they sum up -28 587.16 tonCO2eq.

Finally, it should be highlighted that the production of avocados accounts for higher positive impacts than the production of oranges, and the first ones need less than half of water comparing with the second one, alike to the usage of a reduced agricultural area.

5.2 Climate change scenario

The results for the 2050 scenario are shown in Table 8, indicating the values of pressures and impacts and the percentage of change from the base scenario.

Several points can be highlighted from these results keeping in mind the assumptions indicated in past sections. For example, it was assumed that the golf courses and touristic areas were not going to expand in terms of territory, thus the change of groundwater abstraction for irrigation of these areas was null. Despite of this, the need to pump water from increased depths, caused an increase of 63.29% in energy consumption and the related CO2eq emissions. It is caused by the decrease of precipitation (thus decrease of recharge and decrease of water level), and by the sea level rise (thus the decrease of available freshwater). Thus, even if the volume of groundwater use remains, the aquifer will be under stress in the near future, and this should be kept in mind for policymaking.

The groundwater abstractions for irrigation of crops is the pressure where the negative impacts are expected to increase most (113.62% and 197.43% for the total emissions due to abstracting groundwater from deeper levels for irrigating oranges and avocados respectively), due to decrease in precipitation and sea level rise.

Table 8 DPSIR results for the climate change scenario

Pressure	**Impact in tonCO2eq**	**Variation**
Groundwater abstractions for irrigation of golf courses	-385.10	63.29%
Groundwater abstractions for irrigation of touristic areas	-1267.56	63.29%
Water supply for tourists	-1685.25	8.49%
Wastewater discharge from tourism	-363.73	4.53%
Revenues from tourism	13338563.92	20.00%
Revenues from golf	7220159.54	0.00%
Regulations in Ria Formosa	74108.62	20.00%
Point source pollution from airport	-869.48	21.66%
Water supply for residents	-16482.90	0.00%
Wastewater discharge from resident population	-3935.41	0.00%
Infiltration of fertilizers and pesticides	-4310.88	0.00%
Groundwater abstractions for irrigation of oranges	-400.44	113.62%
Groundwater abstractions for irrigation of avocado	-126.04	197.43%
Production of oranges	258415.53	20.00%
Production of avocado	327230.60	20.00%
Total emissions related to “positive” impacts (revenues)	21 218 478.21	12.35%
Total emissions related to “negative” impacts	-29 826.79	4.34%
DPSIR INDEX (Total emissions)	21 188 651.42	12.37%

It is again interesting to compare two pressures with similar water needs, as wastewater treatment vs. the groundwater abstractions for the irrigation of avocado fields (1.57 hm^3 vs 1.40 hm^3). The impacts associated to the first one are more than twice the second one (-363.73 tonCO2 vs. 126.04 tonCO2), but they have a variation of 4.53% vs the 197.43% variation that presents the groundwater abstractions for irrigation of avocados. Thus, even in a climate change scenario where the groundwater abstractions impacts are very affected due to the necessity of pumping from deeper depths, it has more impact the treatment of wastewater in terms of CO2 emissions.

In terms of assumed projections of tourism and agriculture growth, the extra emissions of "negative" impacts could be covered. However, this is just in monetary terms because seeing the results with wider lens, the results go against the European targets of reducing CO2 emissions for 2050, and thus, the environmental costs cannot be covered.

Figure 14 shows the percentage of each of the emissions associated with negative impacts. The groundwater abstractions for the irrigation the touristic areas, the water treatment for polluted water because of point sources, and the water supply for tourists, increased their percentage of the total emissions in 1% each. On the contrary the water supply for the residents, decreased the contribution to the total emissions in -3%. Finally, groundwater percolation of contaminants, the wastewater discharge from tourism, and the groundwater abstractions for the irrigation of golf courses and oranges crops, remain the same.

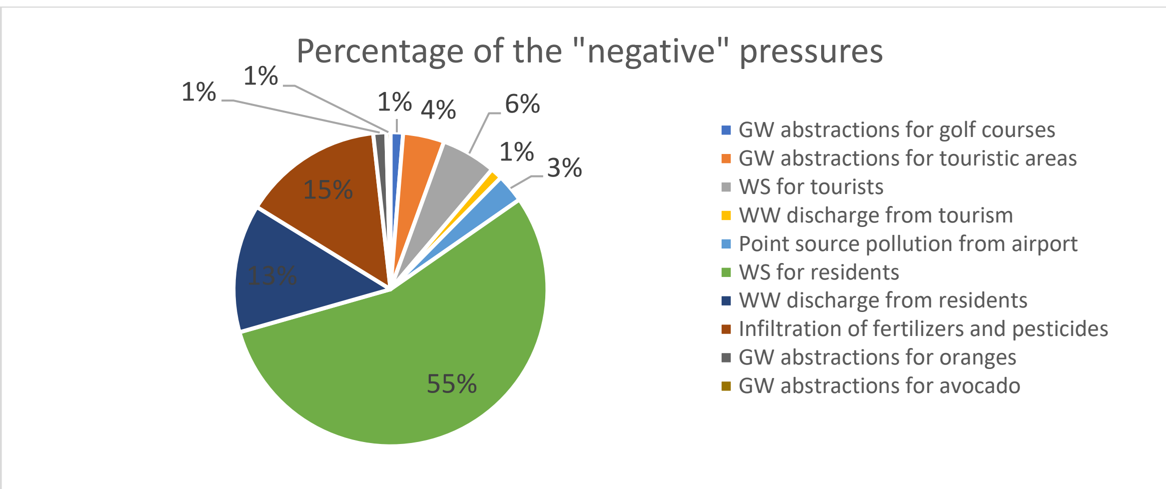

Figure 14 Weight of the pressures that have a negative impact

On the other hand, Figure 15 Weight of the pressures generating positive impacts presents more significant changes between the two scenarios regarding the "positive" impacts in terms of the two main pressures that affect positively: the golf courses and the tourism in general. It can be seen that the first one will have less weight in the total emissions, and the second one will grow in the same amount. The production of oranges and avocados, as well as the revenues from nature conservation will remain the same.

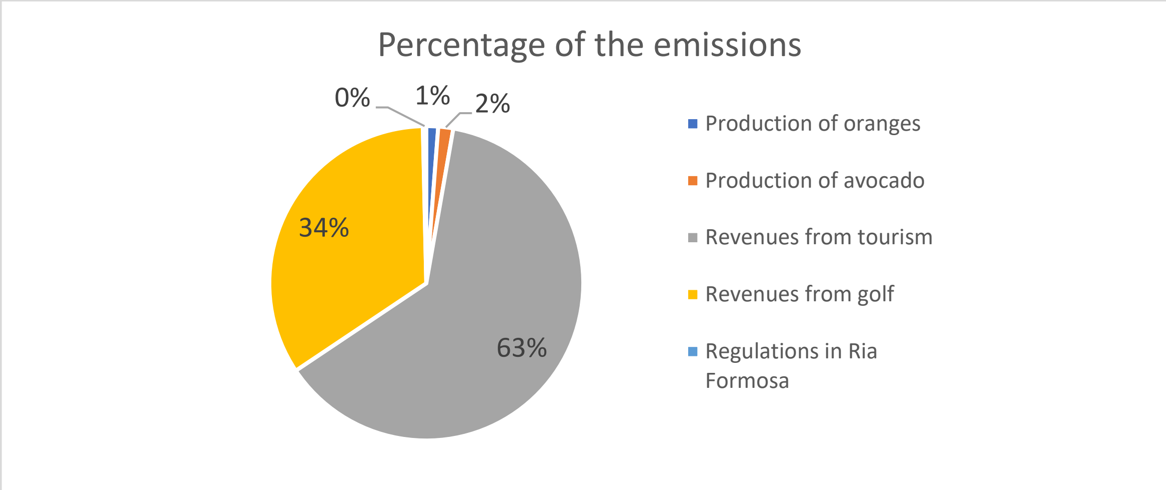

Figure 15 Weight of the pressures generating positive impacts

5.3 Citizen science scenario

The results of the application of the DPSIR model for the horizon of 2050 with the considerations mentioned before (projections and climate change factors), and additionally, the coefficients associated with citizen science, are presented in Table 10. They were obtained by optimizing the value of the coefficients in order to attain in 2050 the same value of the DPSIR as in 2019.

They correspond to a final selection after generating different optimal solutions with the help of solver in Excel, because as it was explained in the "methodology" section, this was an objective-oriented scenario. Thus, Table 9 shows some of the nondominated solutions (or Pareto optimal) which define a n-dimensional frontier where the objective function takes the same value.

Table 9 Response coefficients for the citizen science scenario.

Coefficients (β_i)	Solution				
	1	2	3	4	5
Engagement with the project	0.80	0.60	0.44	0.31	0.23
Sensitivity for spare water	0.22	0.31	0.44	0.61	0.81
Sensitivity for not contaminating groundwater	0.25	0.32	0.43	0.62	0.82
Reduction of the GW abstractions input in the model	0.18	0.19	0.19	0.19	0.19
Reduction of infiltration of pesticides/fertilizers	0.20	0.19	0.19	0.19	0.19

The blue rectangle points the selected solution. It was chosen because there is lack of information on how the engagement with the project will be in reality, the same as how will the sensitivity for protecting the aquifer be enhanced. Thus, a middle term was selected.

Table 10 DPSIR results for the citizen science scenario

Pressure	Impact in tonCO2eq	Variation
Groundwater abstractions for irrigation of golf courses	-312.33	32.43%
Groundwater abstractions for irrigation of touristic areas	-1028.04	32.43%
Water supply for tourists	-1685.25	8.49%
Wastewater discharge from tourism	-363.73	4.53%
Revenues from tourism	13338563.92	20.00%
Revenues from golf	7220159.54	0.00%
Regulations in Ria Formosa	74108.62	20.00%
Point source pollution from airport	-869.48	21.66%
Water supply for residents	-16482.90	0.00%
Wastewater discharge from resident population	-3935.41	0.00%
Infiltration of fertilizers and pesticides	-3483.02	-19.20%
Groundwater abstractions for irrigation of oranges	-324.77	73.26%
Groundwater abstractions for irrigation of avocado	-102.22	141.23%
Production of oranges	258369.27	19.98%
Production of avocado	327433.35	20.07%
Total emissions related to "positive" impacts (revenues)	21 218 634.70	12.35%
Total emissions related to "negative" impacts	-28587.16	0.00%
DPSIR INDEX (Total emissions)	21 190 047.53	12.37%

Considering that in a 2050 horizon in the Campina de Faro aquifer system were climate change is imminent, in which the precipitation will reduce and the sea level will rise, and thus there will be a decrease of groundwater recharge and groundwater table, the solutions that need to be applied for the sustainability of the aquifer must come from the community.

As it can be seen, 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.

5.4 Stochastic analysis

In accordance with the explanations given before about the results presented, which are not definitive values but the means of the most probable values given the statistic distribution that were input, the output of the Oracle Crystal Ball application are presented in Table 11. Moreover, it should be reminded that the citizen science scenario is not presented because it was made with Solver and not with Oracle Crystal Ball. Finally, it must be stated that the spreadsheet was run with a confidence level of 95% in 100000 evaluations.

Table 11 Statistical results from Monte Carlo simulations

	Base Scenario			Climate Change Scenario		
	Emissions	Revenues	Cost of emissions	Emissions	Revenues	Cost of emissions
Min	149.24	423.8	6.11	154.55	484.04	6.22
Max	2828.28	535.94	15.99	3621.47	617.2	22.28
Mean	424.97	472.68	9.72	509.12	541.9	11.65
Median	391.02	472.11	9.63	466.59	541.15	11.44
Mode	269.32	456.32	9.61	332.7	520.77	11.87
St.Dev	156.73	12.95	1.32	203.32	15.82	2.3
Q25	325.44	463.54	8.76	377.33	530.64	9.89
Q75	484.2	481.32	10.59	590.37	552.42	13.18
Q90	599.68	489.76	11.49	741.22	562.82	14.77

These statistics are important to be kept in mind because of the uncertainty of the values that were input to the model. This means that although there is a most probable result, the pressures that are exerted in the Campina de Faro aquifer can have a range of impacts in the strip presented.

5.5 Wrap-up of the main results

After the implementation of the DPSIR model in three scenarios the two main observations can be made for both the current condition of the Campina de Faro aquifer system and the future conditions with or without the participated management:

- The supply of water for residents is the pressure that weight the most in the total value of the index (in CO2eq units), which should be considered for the future allocation of water sources.
- Impacts, which are quantified in terms of CO2 emissions, are not necessarily dependent on the amount of water used but, on the technological processes involved in the life cycle of water use, thus the pressures that require more processes should be better controlled to reduce impacts and increase the sustainability of water resources.

Furthermore, regarding the comparison of the present and future scenarios, we highlight that with a reduction between -25% to -45% of the recharge, a decrease of 28% in the precipitation, and a sea level rise of 0.12 meters, there will be an increase of more than 60% in the negative impacts associated with the groundwater abstractions, thus, without the commitment of the stakeholders (both community and authorities), the value of the index would be higher than in the present which represents that there are considerable CO_2 emissions.

6. Conclusions

6.1 Achievement of the objectives

The main objective of the thesis was achieved which was to develop a quantitative tool based on the concept of the DPSIR frameworks in order to contribute to the eGroundwater project which can be used in the future by actualizing it with new input data.

Moreover, the relationships between the different components of a DPSIR framework were found for the Campina de Faro.

- 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 CO2, and economic impacts.
- Responses: Citizen science and improve stakeholders' sensitivity to sustainable groundwater management.

Finally, current and future scenarios were analyzed, accomplishing the objectives of evaluating the impacts that the climate change will have on the aquifer,assessing the effect of stakeholders involvement in the decision-making process.

6.2 Suggestions and follow-up

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 CO2 in the Campina de Faro aquifer.

Moreover, regarding the eGroundwater project, this investigation throwed some numbers that could be used in the project as targets. These are:

- An engagement of the community in 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.

The first one could be achieved by implementing the recommendations of Pocock which are increasing: the sense of jeopardy, the sense of place, the sense of community, the sense of discovery, and the feeling of being part of a narrative. For this, workshops should continue being done and should be even planned for after the culmination of the project; incentives not necessarily in economic terms should be thought, for example access to information or positions in management movements; explanations should be continued and updated always to date; among others.

Since the project is rather on it’s initial phases, these targets could be set and monitored by taking time series of data of participation, but also by doing polls and interviewing participants regularly, and passing afterwards their responses through processes of like the so called sentiment analysis, which evaluates subjective information from texts in order to identify the atmosphere related to topics in a sample of people.

Finally, it’s important to mention the importance of using Oracle Crystal Ball in models with such high levels of uncertainty as this one, because it allows to record a distribution of probabilities which gives more security when making decisions as there is a stronger back up.

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