Sustainability assessment: Testing and validating a hierarchical framework in the Portuguese wine sector context

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Abstract. Wine-grape growing is extremely vulnerable to climate change impacts for deeply relying on weather conditions. Considering the notable shortage of multidimensional instruments designed specifically to assess sustainability of winegrowing systems, a three-tier hierarchical framework has been developed. This work presents an initial testing of the theoretical framework´s assessment approach, and its capacity to take the context in which the evaluation is taking place into account. For such, after the presentation of general assumptions of the framework, figurative cases of the Portuguese wine industry were evaluated regarding one of the 27 themes of the assessment tool. The theme here tested and presented (theme water use and wastewater) is composed by three sub-themes, with three indicators each. At the end, nine indicators covering from the water footprint, to the wastewater management or local water availability were measured and evaluated. Information gathered and used for this work was based on literature and official sources involved in collecting and elaborating water related data. Results of this initial validation were promising and showed that structured and hierarchical design approaches may be a functional way to holistically assess the sustainability performance of complex production sectors such as the wine industry.

1 Introduction

Wine grape growing is one of the most economically valuable fruit crops in the world and a key source of rural growth for many wine regions, however no question remains regarding the actual challenges the sector is confronting [1,2]. From extreme weather occurrences, together with contemporary socio-economic issues such as rising energy prices, market demands, and new environmental policies, a more resilient and sustainable approach is today compulsory.

Even though wine industry´s issues are not only related to climate vulnerability, its strong link to terroir and weather conditions impels the sector to become more prone to climate change impacts [3,4]. However, such impacts for being specifically tied to regional climatic conditions are expected to be more intense in particular areas of the globe, rather to create large-scale changes. For Mediterranean regions for instance, climate change is expected to have significant impacts including rising temperatures and increased risk of heat stress or sunburn, together with severe droughts and amplified pests and diseases pressure [1,2]. Efficient adaptation strategies are therefore required to ensure the industry's long-term sustainability.

Nevertheless, the sector has been pragmatically addressing sustainability issues since the early 90s, and the urge to have access to better evaluation and decision support tools capable to improve overall sustainability performance is currently on the agenda of most stakeholders. However, several knowledge-gaps prevail as most of sustainability assessments still tend to be environmentally focused, non-context-comprehensive and unfit to evaluate permanent crops such as viticulture [5-7].

Recognising sustainability assessment tools as powerful instruments capable to support informed decision-making and to guide stakeholders to adopt more sustainable practices, their crucial role is here ratified to support the sector’s transition towards sustainability.

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Therefore, a three-tier hierarchical framework has been developed for the wine industry, to holistically assess wine businesses sustainability performance, considering environmental, social and governance (ESG) risks or opportunities.

For the critical requirement to link the context in which the system being evaluated operates, the purpose of this work is to perform an initial testing through figurative cases of Portuguese winegrowing businesses.

For simplicity´s sake, this paper only presents the validation of one of the 27 themes being assessed by the proposed framework, however these initial testing steps can easily be replicated to all the other themes. The theme here presented and tested is Water use and wastewater, a pertinent topic for the Portuguese wine sector context.

The decision to proceed with this initial testing of the framework´s applicability to the Portuguese context has also value for the country´s long-established history of wine production. Despite being a small country in western-Europe, Portugal is one of the biggest acclaimed old world wine countries, ranking fourth in the EU by vineyard area (ninth in the world), and fifth by volume of produced wine (tenth in the world) [8]. The wine sector is therefore highly meaningful to the Portuguese socioeconomic landscape, and for the development of its rural societies [9,10].

Nonetheless, Portugal being under the Mediterranean region's spectrum is under serious climatic threat with great challenges ahead for viticulture [1,2]. Besides warming trends, changes in precipitation patterns are also expected with some areas experiencing increased rainfall, and others severe droughts with significant impacts on crop yields and quality [11]. In recent years, droughts and water shortages have become increasingly common in Portugal with the wine sector being negatively impacted, particularly in regions where irrigation is limited. Moreover, it is also acknowledged that the water use of the wine industry can be relatively high. To attain sustainable winegrowing systems, it is seen as essential to also ensure water sustainability, thus the relevancy of the theme here being tested for the Portuguese wine sector.

To close, as agriculture continues to be the largest user of freshwater, improving water efficiency in agriculture is critical to impact water scarcity, food security and climate change. The global agricultural water withdrawal represents the majority of the total global freshwater withdrawals, and of this around 70% is estimated to be used for irrigation purposes [12]. In Portugal, agriculture accounts for 75% of all water used, given the need for irrigation in crop production [13]. Even though some vineyards in Portugal are still dry-farmed (or rain-fed), as water scarcity is becoming a major concern in many parts of Portugal, and projections show yield decreases up to 80% of baseline yields, the Portuguese wine industry is today aware of the upcoming challenges and is starting to see irrigation as an adaptation measure to ensure the future sustainability of viticultural yields [14]. It is therefore primordial to assure sustainable water management practices and more efficient water uses.

Results of this initial validation test are promising and offer constructive insights for further developments and improvements.

2 Materials and methods

2.1 The three tier framework

The three-tier assessment framework proposed for the wine industry is a holistic approach to help firms to comply with new sustainability policies, export market pressures, and meet emergent accountability requirements. Assessment themes range from human rights and labour standards, to economic viability, product quality, land use change, climate change and water sustainability among others.

The framework´s is aligned to the four principles of sustainable agriculture identified in Trigo et al. [15]: integrated management; dynamic balance; regenerative design; and social development, together with the set of five principles established by the International Organisation of Vine and Wine (OIV) to promote sustainable wine production [16]. The PSR model based on pressure-state-response theory was also established to assists in the identification of relevant sustainability indicators [17], together with a matrix process. Matching principles established for the wine industry, sustainability goals and major concerns, the framework´s structure is then threefold organised into: Environmental-social-governance dimensions (ESG); nine key properties or criteria; 27 themes; 81 sub-themes; and 243 indicators. This stratification allows for each sustainability attribute to be evaluated individually if intended, using indicators that better relate with the end-user purpose and available resources for data gathering.

2.2 Assessment approach

As for the framework´s assessment approach and rules, each component can be evaluated one by one, however to be able to reach the final ESG score, there are core sustainability indicators (CSI) that must be assessed. Such CSI are also relevant to track another tool's set of indicators, the key sustainability indicators (KSI).

KSI are typically based in revised indexes or composite indicators, easy to comprehend and communicate to stakeholders. The goal is to also provide the end-user with a communication tool that can be used for sustainability reporting of the organisation's performance.

Moreover, considering lack of data issues, the majority of indicators are complemented with supplementary components to support measurement and decision-making. Such supplementary indicators should be used to complement the monitoring of this indicator, even if associated to other sub-themes. When interpreting these indicators, it should be kept in mind that they must be read in connection with other indicators of the tool and further information not directly related to the topic may be necessary. The effect of management practices are also indirectly evaluated through questionnaires using management practices indicators (MPI). These are parameters often 'ticked off' in sustainability wine programs or other sustainability standards. A questionnaire-based interview with the farm manager is the main source for gathering necessary information. All the KSIs and MPIs used to assess the theme water use and wastewater, can be accessed in Appendix 1 and Appendix 2, respectively.

Regarding the normalisation and aggregation process, based on the principle of dynamic balance [15], equal weights are assigned to all indicators in order to provide a more comprehensive and holistic view of the company´s performance. All the components of the tool, from indicators to themes and dimensions are therefore given the same weight and average aggregated. Such decision allows an even distribution and provides a well-balanced ESG sustainability score. At the same time an impartial and equitable assessment over the short and long term can be guaranteed, regardless the variability amongst regions, or even biased evaluations potentially influenced by personal beliefs or organisational interests.

Once the indicators are measured, the score is normalised to a scale of 0-100 through comparison between industry benchmarks and reference data of the context under evaluation. Depending on the nature of the indicator, score 100 may represent the lowest pressure, or the highest performance, with the resulting values ranging from an optimum 100 points to a completely unsustainable situation of 0 points.

Finally, average scores for each subtheme are again average aggregated into a final score positioning the end-user into three sustainability classes (i) problematic/unsustainable position (0-33 points); (ii) sustainable with some restrains (34-66 points); (iii) fully sustainable/optimal position (67-100 points). Even though some sustainability assessments (e.g. INSPIA) only regards results above 67 points as sustainable [18], this framework follows the threshold used in RISE, a response-inducing sustainability evaluation [19]. The aim is to offer through the results, not only comparative evaluations of the sustainability degree of different wine producers, but also to offer a holistic approach for individual advice, education and planning for improvement.

2.3 Theme "water use and wastewater"

However, before the three-tier assessment tool being reworked and presented to a broader public, it must be tested and validated at different stages appropriate to the wine industry for which it was designed. As aforementioned, this paper presents the initial testing using figurative cases of the Portuguese wine industry to validate one of the 27 themes (water use and wastewater). Nevertheless, each validation step here illustrated can be replicated to the other remaining themes.

This theme together with other two themes assess the circular economy performance of the end user. Thus, the company´s circular economy performance score is the average result of: (1) Water use and wastewater; (2) Climate smart packaging and materials; and (3) Waste and waste management. This property is part of the environmental dimension. The water use and wastewater theme (1) is divided into three sub-themes: (1.1) water use; (1.2) wastewater; and (1.3) water quality & availability, each with indicators based on the PSR model. As defended in [20], using PSR model to assist in the identification of relevant sustainability indicators not only it structures and classifies information, but by developing cause-effect relationships sketches a logical pathway for decision-making.

The data used for this initial testing was based in average results obtained from previous studies performed among the Portuguese wine industry, together with available industry benchmarks. A series of global boundaries and targets that frame the indicators under evaluation were also considered, such as the Planetary Boundaries (PB), Sustainable Development Goals (SDGs), European Green Deal (EGD), the European Union Water Framework Directive (WFD), among others (e.g. U.S. Clean Water Act; Canadian Federal Water Policy; World Health Organisation Guidelines for Drinking-water Quality). Thus, both the figurative cases´ values and the thresholds establishing the limits are based on results and criteria drawn from the literature.

This approach supports the process of tracking the progress towards sustainability. For this particular theme, the assessment has relevancy for the SDG 6 with the aim to ensure availability and sustainable management of water for all by 2030 [21]. The same relevancy for the Water Framework Directive aiming to achieve "good status" for all EU surface waters (rivers, lakes, transitional and coastal waters) by 2027 [22]. On the other hand, regarding the nine PB identified in 2009 by a group of scientists led by Johan Rockström [23] where the freshwater boundary was set to an annual maximum of 4,000 km^3 consumptive blue water use, a new study published in 2022 reported that the boundary now updated to include the green water, has been considerably transgressed [24]. Making six out of nine planetary boundaries already crossed until this moment.

3 Test construction and results

3.1 Sub-theme "water use"

To assess the first sub-theme on the water used by the wine company, three indicators are measured and evaluated: water footprint (state indicator); water withdrawn and consumed (pressure indicator), and water use efficiency (response indicator).

3.1.1 Water footprint

The water footprint (WF) refers to the amount of water used throughout the winegrowing production process, including irrigation of vineyards, cleaning and sanitation of the processing equipment, and bottling [25]. WF generally takes into account three components: the green, blue and grey water footprint. The green water footprint (WFgreen) is the volume of rainwater that is evapotranspirated or stored into the soil as soil moisture. The blue water footprint (WFblue) is the volume of freshwater withdrawn during the process. The grey water footprint (WFgrey) is the amount of fresh water required to assimilate pollutants to meet specific water quality standards, therefore an estimate of a virtual volume [25,26].

The results provided by the Water Footprint Assessment Tool regarding annual green, blue and grey water footprint of all sectors and crops in Portugal, evidenced that grape production represents 9% of the total national water footprint, with green water representing 12%; blue water 2%; and grey water 4% [27].

However, according to literature, the largest water consuming phase in the wine production process is the wine-grape growing process. Studies have mentioned a global average WF of grapes being around 610 L/kg, with the WF associated with vineyard representing until 97.5% of the total WF, even though the winery stage can be responsible for more than 75% of the global warming potential indicator [28,29].

In Portugal, very few studies have been conducted to estimate viticulture WF. Quinteiro et al. [30] recorded that 400 L-500 L of freshwater use is associated with the production of one 0.75 L bottle of Portuguese white wine from the Vinhos Verdes Region. Another study based on field experiments on two Portuguese case studies in the south of Portugal (Tejo and Alentejo regions) showed WF values from 366 L to 899 L/0.75 L wine [28]. When only assessing the winery WF, Martins et al. [31] performed a sustainability evaluation of Portuguese wines based on the life cycle assessment (LCA) methodology. The authors reported water consumption ranging from 1.58 L to 4.93 L of water/0.75 L wine for the 'terroir' wine and 'branded' wine respectively, with similar differences being observed between the wastewater values of the two wines. Regarding the effective efficiency of the wastewater treatment system and estimation of its overall impact on the winery water footprint, another study assessing a medium-sized winery located in the south of Portugal (Tejo wine region), with a production capacity of 750,000 L showed WF values ranging from 9.6 L to 12.7 L of water per wine bottle of 0.75 L, with the wastewater produced being responsible for about 98% [32].

Bottom line, WF of the wine industry can vary deeply, depending on the business location and the type of wine being produced. Taking into consideration that published WF values range on average from 300 L to 800 L of water per L of wine produced [29], the threshold for this indicator is 300 L/L (max. score 100) to 800 L/L (min. score 0).

3.1.2 Water withdrawn and consumed

Regarding the water withdrawn and consumed indicator, the main water source being used is seen as critical to take into account. This indicator is classified as KSI for being part of the circularity index (KSI of the property 3.2. Circular economy). The circularity index is a metric that measures the extent to which a company or industry is adopting circular economy principles, promoted by the Ellen MacArthur Foundation [33]. Thus, for measuring the water withdrawn and consumed, the percentage (by volume) of annual water demand from different water sources is accounted (see Appendix 1 for Circularity Index - Theme 9 water). The use of potable water from freshwater sources or any freshwater sourced from areas classified as water-stressed is associated to the lowest score (min. score 0).

Regarding the variable of water sources, surface water and groundwater are the main sources used in Portugal. Surface water includes water from rivers, lakes, and other surface water sources. Groundwater includes water from underground aquifers and wells, being usually used for irrigation in areas where surface water is scarce or not available. Similar to other countries, the agricultural sector is the largest water user, accounting for 80% of total water abstractions in 2018 [34] and for 76% of groundwater withdrawals in 2010 [35]. Agriculture in Portugal also accounts for significant pressures on surface waters and groundwater bodies due to diffuse pollution, with 42% of surface water bodies and 22% of groundwater bodies being affected [34].

3.1.3 Water use efficiency

This indicator is also critical for the increasingly dry and hot weather conditions projected for the next years, and the need to take action by developing adaptation strategies. Several studies have measured the effects of water stress on grapevine growth and yield, the impact of irrigation strategies on water use efficiency and productivity, and the usefulness of various techniques for measuring water use efficiency in vineyards. According to GRI [36], water has critical importance to agricultural productivity and on average, irrigated land is twice as productive per unit as non-irrigated land.

In Portugal, a study testing the effects of vineyard soil management practices combined with deficit irrigation strategies on the performance of a vineyard, showed that in dry areas with low vigour vineyards, the combination of resident vegetation with deficit irrigation treatments should be carefully considered as it can reduce yield without any benefits to grape quality [37]. The conventional sustained deficit irrigation was considered ideal for this particular scenarios. On the other hand, even though drip irrigation often results in the highest water use efficiency and grape yield, it is also associated to higher capital costs and energy demand.

More recently, it was projected that, for some wine regions in Portugal, such as the Douro wine region where dry-farming is widely used, climate change will cause a considerable yield decrement. Even with irrigation it is expected 70-80% of baseline yields, though to a lesser extent when compared to non-irrigated simulations [14]. The urge to build climate resilience is therefore eminent.

To measure water use efficiency indicator (WUE), the plant water requirement can be considered (annual vineyard water requirement or growing season water requirement) for being essential for determining optimal irrigation systems, the irrigation schedule and water application rate. In addition, a variety of complex and multifaceted factors can also be taken into account, such as the evapotranspiration (ET) together with visual observations in the vineyard to spot water stress. One way to calculate the WUE is through the ratio between yield and the volume of water provided to the vineyard through irrigation and rainfall [38].

However, other metrics can be used, such as Net water consumption (NWC). Even though water use at the winery is often less representative of the overall WF for no contribution to green water footprint value from the winery [39], to measure this variable in some circumstances can be important step towards water sustainability as it allows users to identify inefficiencies in the production system. Besides, the water impact of the winery can vary deeply due to the location where the assessment is taken place, as some regions may be more prone to water scarcity or even subjected to regulations or compliance requirements.

According to literature, the typical WUE value for irrigated vineyards ranges from 2 to 3 kilograms of yield per cubic meter of water applied (kg/m^3). However this values can vary widely for various factors including the irrigation management system [38,40,41]. For that reason the threshold for this indicator was limited to 1-4 (kg/m^3).

3.2 Sub-theme "wastewater"

To assess the second sub-theme regarding wastewater, another three indicators are measured: wastewater generated (state indicator); wastewater management (pressure indicator), and wastewater reuse/recycling practices (response indicator).

3.2.1 Wastewater generated

For this indicator it is considered the volume of water that is polluted or consumed during wine production, taking into account if possible, both direct and indirect sources of wastewater. Winery wastewater (WW) is typically generated from washing operations during grape harvesting, processing and vinification, as well as from bottling.

Grey water footprint, despite often a minor component of the total WF, it is directly associated to pollution and degradation of the water resource [39]. Thus, particular care is being dedicated to the evaluation of the grey water component as the wastewater footprint can be the second largest contributor to the overall environmental impact of wine production, after greenhouse gas emissions [42]. Besides, as the winery WW production is not regular year round varying in terms of seasonality, quantity, and quality, the depolluting treatments should also be highly flexible [39].

Even though the amount of WW generated by the wine industry can vary widely based on specific winemaking operations and the volume of wine being produced (when the volume increases the ratio of wastewater to wine production often decreases), the threshold for this indicator takes into consideration the four benchmarking zones of WW generation proposed in Aybar et al. [43]. Based on French, US, and Chilean winemaking reference target ratios, where the French industry consistently shows wastewater generation ratios similar or lower than 1 L of wastewater per L of wine produced, it is established a threshold between 0 L and 12 L of wastewater per L of wine produced, with 0 L/L representing the higher score of 100. This target is feasible as, according to Lamastra et al. and Mekonnen & Hoekstra [25,29], the grey water footprint can be equal to zero if an efficient depurator (or efficient wastewater treatment plant) is used allowing to return the water to the environment with a pollutant load below the given pollution level authorised.

3.2.2 Wastewater management

Winery WW is characterised by high organic loadings, with ethanol and sugars representing more than 90%. The average biochemical oxygen demand (BOD), the chemical oxygen demand (COD) and total suspended solids (TSS) are typically high. COD values ranging between 800 and 12,800 mg/L, but can go up to 45 000 mg/L, BOD ranging between 7,000 and 10,000 mg/L, and TSS over 3,000 mg/L [43-45].

WW is also characterised by low pH and high concentrations of nitrogen and phosphorous, leading to the need to implement adequate wastewater treatment techniques to reduce the impact in its discharge in the environment, or comply with local regulations. In short, treatment and disposal of WWs can be one of the main environmental problems in the wine industry demanding caution in its management [45,46].

However, most wineries do not have sophisticated wastewater treatment systems to deal with their high strength wastewater. For that matter, to measure the wastewater treatment system efficiency was considered relevant for this indicator. Several parameters can be taken into account to measure the performance of the wastewater treatment system being used, in terms of its efficiency [43]. For this efficiency measurement, the indicator is expressed as the percentage of pollutant removal achieved by the treatment process (mainly BOD and COD levels). Other parameters such as total suspended solids, nitrogen compounds, phosphorus, heavy metals, organic and inorganic contaminants, pH, and turbidity, can also be used to assess the wastewater quality [43].

For the indicator threshold, legal requirements both for recycling or disposal are taken into account. Once again, this indicator is in accordance to the context in which the evaluation is taking place, as legislation differs among countries. For instance, while the Portuguese legislation sets maximum values of 10-40 mg/L of organic matter expressed as BOD, for wastewater reuse in crop irrigation, more restrictive countries only allow the use of WW with 20-30 mg/L expressed as BOD. COD concentration should be inferior to 200 mg/L [47].

Finally, this indicator can also be used to calculate the circularity index (KSI of the property 3.2. Circular economy) regarding the water discharge conditions and monitoring (9D. wastewater management), and for that matter is classified as KSI.

3.2.3 Water reuse and recycling

The last indicator of the wastewater sub-theme takes into consideration one important strategy for the wine industry to minimise its water footprint and environmental burden. The possibility, if properly planned and controlled, to reuse the winery WW. OIV has already reinforced in its principles the need to consider recycling or reuse by the industry to reduce the impact on the environment and on public sewer networks [16].

Wine-producing countries, in particular those subject to significant water stress, are today exploring this alternative, as wastewater recycling appears to be both financially and technically sustainable. It is pointed as a strategy of water management with high added value [48]. Even though water recycling and reuse can be implemented by almost any country, in Europe a small percentage of treated wastewater is being reused.

The percentage of water already being reused by the wine company is therefore considered to assess this indicator. There are several ways the wine industry can reuse and recycle water which are considered when measuring this indicator. Considering the fact that Portugal has set a target of reusing 10% in 2025 and 20% in 2030 of treated wastewater [49], the threshold for this indicator measuring the percentage of water recycled in the production process is set for 0-20%.

Water recycling and reuse includes direct reuse (WW clean enough to be reused several times) or recycled WW when first needs to be treated. It is therefore important to ensure that the quality of the reused water is suitable for the intended purpose (irrigation, washing, cleaning, pH adjustment, fire protection, cooling or heating purposes), and that it does not harm the environment or public health when discharged. On the other hand, even though ensuring WW microbiological quality is essential, care should also be taken for not reducing its nutrients (mainly N, P and K) as valuable inputs [48]. Another parameter being measured for this indicator also focus on nutrient recirculation and recovery technologies (classified as KSI as indicator 9C of circularity index is used).

This is seen as a critical topic and compatible with the EU's Farm to Fork strategy, aiming to reduce nutrient losses by 50% by 2030 and fertiliser use of at least 20%, as the contribution of treated WW to fertilisation-needs of the vines can be a significant strategy on the pursuit to reduce inorganic/synthetic fertilisers' use [48].

New water reuse regulations in EU are being structured to encourage circular approaches to water reuse in agriculture, according to the new Circular Economy Action Plan. Additionally, an Integrated Nutrient Management Plan will also ensure and stimulate more sustainable application of nutrients and assess nutrient removal techniques (such as natural means using algae) [50]. It will demand the development and use of effective and accessible alternatives for WW treatment, so small/medium wineries can accomplish legal requirements for recycling or disposal [47].

3.3 Sub-theme "water quality and availability"

To assess the third and final sub-theme, indicators such as water availability (state indicator); water quality (pressure indicator); and the impact on local water supply (response indicator) are evaluated. This sub-theme is particularly based on systems theory for recognising the interconnectedness of wine companies with their surrounding environments [51]. It is defended the need to guarantee satisfactory water quality in inputs to the water supply reservoirs, the maintenance of local aquatic ecosystems, along with sustainable water availability for agricultural use, recreation and in-stream domestic water supply. This point is also in agreement to OIV principles for sustainable vitviniculture where it is defended that the use of water should be considered in terms of its local availability and impact on water quality and groundwater table levels [16].

3.3.1 Water availability

Congruent with current incremental rates of agricultural demands on the world freshwater resources, the wine industry too relies often on access to freshwater resources. Predictions regarding climate change show an overall decrease in the availability of freshwater in the majority of wine regions, in particular from the Mediterranean basin. The continuously increasing demand for water coupled with its misuse is therefore seen as unsustainable.

As the distribution of freshwater resources is not homogeneous and variations in water availability are strongly related both to the place and time, such aspects must be taken into account [39]. The frequency and duration of water shortages or disruptions are translated into the level of water scarcity risk of the context in which the evaluation is taking place, together with the water demand or overexploitation by the wine company (particularly freshwater use).

For such, the freshwater Withdrawal-To-Availability (WTA) ratio (ratio of total withdrawals to total renewable supply in a given area) is used at national level to define the current water scarcity level [52]. Regarding Portugal´s water scarcity risk and water availability, information on Total Actual Renewable Water Resources was used [53]. It has been also reported that the country has very low rates of groundwater availability, and is currently categorised as high risk of water scarcity for continuously using at least 40% of national water reserves every year [54].

Considering methodological shortcomings identified among literature pointing limitation for only using the water WTA ratio to characterise the water scarcity risk [55], a second metric is included. Thus, water availability is here measured considering climate change and land use change. The actual usage of freshwater by the wine company, expressed as the percentage of water withdrawal from freshwater sources. The threshold for this metric is based in the country's surface and groundwater availability.

3.3.2 Water quality

Protecting and improving water quality are key fundamentals. Appropriate risk management measures should be implemented in-site to protect the quality of water resources. Based on literature, several modelling and statistical analysis are used for risk assessment in order to evaluate the potential risk of water contamination.

The exposure toxicity ratio (ETR) is one of the approaches used as it provides a quantitative measure of the relationship between exposure and toxicity. Fragoulis et al. [56] also used this concept in the organic viticulture indicator (EIOVI) in order to measure environmental potential risks, in particular the ground water, surface water and soil exposure toxicity ratio.

The Exposure Toxicity Ratio (ETR) is often used to evaluate the potential for adverse effects from exposure to contaminants in water sources. ETR values are specific to the individual case as depend on a range of factors, including present contaminants, toxicity thresholds, exposure pathways, and vulnerability of the water sources. To measure the water contamination risk through ETR approach, nutrient contamination risk and pesticide contamination risk are often measured as the ratio of the potential contamination concentration (mg/L) to the maximum allowable concentration (mg/L). Several approaches can be considered, including site inspections and assessments, along with water and soil quality analysis [57].

In short, to measure the risk of water contamination from agricultural activity, metrics encompassing nitrates, phosphates, and pesticides should be considered. For this indicator in particular, considering nutrient emissions (primarily nitrogen and phosphorus) as major contributors to water contamination, particularly in groundwater and surface water sources, ETR values for nitrate and phosphorus pollution are accounted. According to literature, nitrate pollution in groundwater and surface water leads to terrestrial and freshwater acidification, while the presence of phosphorus in agricultural runoff can accelerate eutrophication [18,36,58,59].

The threshold of ETR values range from 0 to 1, with 1 as the worst score (min. score 0) as it indicates that the exposure concentration of a particular contaminant is equal to the toxicity threshold.

3.3.3 Local water supply

Inefficient or misuse of water supply can be responsible for depletion of aquifers, river flows reduction, wildlife habitats degradation, and land lost to salinisation and waterlogging. On the other hand, beneficial impacts can take place if protection and regenerative practices are adopted [39]. It is therefore relevant to also assess how sustainable the company´s water management strategies are impacting the local water supply, by also considering local water stakeholders needs (residents or other agricultural water users).

Several parameters are often used, such as the population density, per capita water availability or alternative water sources. Societal responses to water quality and availability issues in the form of measures constraining the water available have also been proposed, despite inherent limitations and shortcomings. One of the possibilities is to measure the water price trend and the charges for wastewater treatment. However, data on water prices and user charges may only be partly available in some circumstances, and therefore it is designated as one of the supplementary indicator [60].

As for local measures constraining the overexploitation of freshwater sources, examples as groundwater licensing imposed by regulatory authorities to monitor and control the utilisation of groundwater resources, can be an effective way to measure this indicator. Nonetheless, this point also varies widely according to location as in certain countries wells can either be exempt from groundwater licensing or must only be declared. In Portugal for example, licencing limits can be based on the horsepower of the water pump (5 hp. discharging less than 30 m^3 /h) [61]. In addition, cases of illegal water use (unauthorised extraction or use of water without proper permits or licenses) are still a problem among several countries, affecting not only the environment but also the legal users' suppliers and local population [62]. Recent controversies regarding this issue involve the illegal drilling of wells in the Doñana National Park, a UNESCO World Heritage site and an important ecological zone in Andalusia, Spain. This has been a considerable hardship for Spain, as overall at least 500,000 illegal wells have been identified, which means that the amount of groundwater being extracted illegally each year equals to the average water consumption of 58 million people [62].

Thus, to measure this indicator it was considered the fact that the world is not on track to meet the water-related SDGs and their targets [63], which calls for urgent action and cooperation to restore ecosystems (land and freshwater areas). Thus, inspired in the recently adopted Kunming-Montreal Global Biodiversity Framework (GBF) agreed at the Convention on Biological Diversity (CBD) at COP15, to evaluate the response to local water supply impact the hectares of freshwater ecosystems restored by the wine company are considered. The threshold is based on the established target of ensuring at least 30 per cent of areas of degraded terrestrial, inland water, and marine ecosystems are under effective restoration.

Finally, the volume of freshwater withdrawal reviewed for smart reduction targets is conjointly assessed as another KSI for the circularity index.

3.4. Results and final scores

Table 1 summarises the assessment approach of the theme water use and wastewater, with final scores for the three figurative cases.

Table 1. Final test scores of 'water use and wastewater' theme.

Sub-theme	*Indicator*	*Variable*	*Unit*	*Threshold*	*Score C1*	*Score C2*	*Score C3*
Water use	water footprint	GreenWF; BlueWF; GreyWF	L/L	300-800	79	52	18
	water withdrawn and consumed	KSI. 9A. water source	%	0-100	20	5	20
	efficient water use	WUE	Kg/m3	1-4	40	87	100
Total score					*46*	*48*	*46*
Wastewater	wastewater generated	GreyWF	L/L	0-12	93	41	63
	wastewater management	BOD; COD; TSS removal efficiency	%	0-100	79	93	80
		KSI. 9D. wastewater management	%	0-100	100	100	100
	wastewater reuse&recycling	recycled water used in production	%	0-20	100	0	0
		KSI. 9C. nutrient recirculation	%	0-100	50	50	25
Total score					*84*	*57*	*54*
Water quality and availability	water availability	water scarcity risk (WTA)	%	1-5	25	25	25
		withdrawal from renewable water resources	%	0-100	80	90	60
	water quality	N, P contamination risk (ETR)	mg/L	0-1	20	0	60
	local water supply	protected/restored freshwater ecosystems	%	0-30	17	3	33
		KSI. 9B. Freshwater withdrawal smart reduction targets	%	0-100	80	20	40
Total score					*44*	*28*	*44*
Final score					**58**	**44**	**48**

As shown, even though all three cases scored between 34 and 66 points, being therefore regarded as sustainable with some restrains (see Sect. 2.2 assessment approach), some clearly have more constrains that require caution than others. While the first figurative case (C1) shows higher scores in almost all sub-themes, rising to an optimal position on issues regarding the winery wastewater sub-theme (84 points), the other two figurative cases, in particular C2, show some fragilities associated to water quality and availability. By only scoring 28 points in the third sub-theme, is in serious risk to drop to an unsustainable position if further action is not taken.

Based on C2 individual scores, it is advised to look for alternative water sources to supplement the ones currently being used, either by installing rainwater harvesting structures or implementing wastewater recycling systems. Also, considering its nitrate pollution risk, and limited restoration action on freshwater ecosystems, it may be beneficial to consider the establishment in-farm of riparian buffer zones along water bodies for their capacity to improve water quality by filtering runoff water.

Finally, for major challenges and concerns associated to the context under evaluation, the considerable withdrawal of potable water from freshwater sources, in particular when dealing with areas classified as high risk of water scarcity such as Portugal, should be seen as one of the main priorities to be addressed by the Portuguese wine industry. Rapid and ambitious efforts to reduce the industry's water footprint by implementing more efficient irrigation practices or adopting water recycling systems in-site should be promoted and encouraged through better water management policies.

4 Conclusions

The validation process of any assessment tool is an important step that should be taken at various stages of its development and use. Here we present an initial testing of one of the 27 themes of a sustainability assessment tool designed specifically for the wine industry. The main goal was to validate its assessment approach, together with the capacity to take the context in which the evaluation is taking place into account. This process can easily be replicated to all the remaining themes as their structure follow the same framework model. For this particular work, figurative cases of the Portuguese wine industry context were considered. Both performance values, and indicator thresholds were based on literature and available official information shared by national and international agencies.

The results of the validation of the indicator were promising, as the assessment approach revealed to be functional and context-comprehensive. Furthermore, even though some indicators request quantitative assessments using data that are not always available for the end-user, by proposing metrics often expressed as percentages or capable to be measured through questionnaires (supplementary indicators and MPIs) makes this tool more accessible to a wider range of decision-makers. Finally, this work also shows how a structured hierarchical design approach may answer to the need for more and better integrated methodologies when holistically evaluating complex production systems on sustainability.

Nevertheless, considering the importance to test this instrument in the field and consult experts' opinions, further validation processes will be implemented following the methodological framework developed by Bockstaller & Girardin [64] where three conditions of validation are considered: design validation; output validation; and end-user validation.

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Appendices

Appendix 1. KSIs for the theme "water use and wastewater" (Circularity Index).

Circularity Index – 9. Water
9A. WHAT % (BY VOLUME) OF YOUR ANNUAL WATER DEMAND (AS STATED IN 0X. PART 1.) IS FROM EACH OF THE FOLLOWING SOURCES:
100% Precipitation harvesting.
100% Cascading use of water (direct use of untreated wastewater, in a manner that is safe for the environment and human health).
100% Internally recirculated water.
100% Seawater.
100% Non-potable water from freshwater areas that are not classified as water-stressed.
0% None of the above (e.g. potable water from freshwater sources, any freshwater sourced from areas classified as water-stressed).
0% Data not available
9B. FRESHWATER WITHDRAWAL REDUCTION
WHICH % (BY VOLUME) OF YOUR WATER WITHDRAWAL HAVE YOU REVIEWED FOR SMART REDUCTION TARGETS?
9C. TO WHAT EXTENT DO YOU HAVE PLANS IN PLACE TO EXTRACT SURPLUS NUTRIENTS, METALS, CHEMICALS, HEAT AND SIMILAR VALUABLE RESOURCES BEFORE DISCHARGING THE WATER USED IN YOUR PROCESSES AND OPERATIONS?
0% Have not assessed yet.
25% Have assessed, currently developing plans.
50% Processes in place for some of the water used in operations, or for some of the relevant resources.
75% Processes in place for majority of the water used in operations and for majority of the relevant resources.
0% Data not available.;
WITH PROCESSES IN PLACE TO EXTRACT SURPLUS NUTRIENTS, METALS, CHEMICALS, HEAT AND SIMILAR VALUABLE RESOURCES FROM WATER USED IN OPERATIONS, ARE THE MAJORITY OF THE EXTRACTED RESOURCES SUBSEQUENTLY RECIRCULATED (E.G. THROUGH HEAT EXCHANGE, AS NUTRIENT RECIRCULATION THAT MEETS THE QUALIFYING CONDITIONS, ETC.)?
25% Yes.
0% No.
0% Data not available
9D. WHAT % (BY VOLUME) OF WATER ANNUALLY USED IN YOUR OPERATIONS LEAVES YOUR INFRASTRUCTURE* (AS STATED IN 0X. PART 2.) IN THE FOLLOWING WAYS: * Including third party monitoring and treatment
100% For reuse elsewhere (as part of symbiosis, cascading).
100% Fulfilling all of the following requirements: • After volume monitoring. • AND quality monitoring, ensuring the same or higher quality than the surrounding (healthy) ecosystem. • AND in the case of original freshwater, to one of the following purposes: • recharge local aquifers/groundwater. • replenish rivers/lakes/wetlands. • local societal purposes (e.g. drinking water supply). • AND in the case of original saltwater, back to a saltwater body.
0% None of the above, including any water discharge without water quality monitoring and any water discharge without quantity monitoring. Water discharge of original freshwater to a saltwater body also counts towards this response option. This also includes evaporation or spillage.
0% Data not available.;
Source: Ellen MacArthur Foundation [31]

Appendix 2. MPIs for the theme "water use and wastewater".

3.2.3. Water use and wastewater - MPIs	
Type of water use in the vineyard	
dry-farming/rain fed	100
precision irrigation system	50
0% none of the above (e.g. by gravity or flooding).	0
0% data not available	0
In case of precision irrigation, which type of material is used?	
drip	100
micro-sprinkler	75
winder or sprinkler irrigation	25
irrigation pivot	25
0% data not available	0
Water efficient use practices: use of advance precise irrigation methods	
conventional deficit irrigation (conventional sustained deficit irrigation)	100
regulated deficit irrigation	100
partial rootzone drying	100
0% none of the above (e.g. potable water from freshwater sources, any freshwater sourced from areas classified as water-stressed).	0
0% data not available.	0
Efficient vineyard water management. Please check all that apply. Final result is the sum of answers	
No new drainage infrastructure of plots during last 3 years	10
A water book register (current water consumption, type of irrigation, date) specify the water consumption reading (m) or the estimation needed for each irrigation episode	10
Consultation of irrigation newsletters (period and quantity for each region); weather forecast and agro climatic indicators (potential evapotranspiration, rainfall, balance between rainfall minus evapotranspiration, number of days during june >= 25°c, relative irrigation supply = irrigation volume/(evapotranspiration - rainfall)...)	10
Use of irrigation management tools at soil level (superficial soil observation, soil sampling for hr% content, tensiometric sensor, capacitive probe) and use of irrigation management tools at plant level (sap flow sensor, apex method, plant/crop visualization)	10
Use of system of rainwater harvesting	10
Use of seeds and planting material (as well as grafting material) adapted to local conditions (drought periods, ...)	10
Updating of the irrigation management according to the watershed management plan yearly revised	10
Irrigation management strategy: define an irrigation management strategy and determine a monitoring plan of the same;	10
Monitoring and correction of irrigation water quality: define an analysis plan that includes quality parameters	10
Management and control of water volume applied and monitoring of irrigation need: carry out action and monitoring plans in order to guarantee the improvement of penetration of water into the soil.;	10
Water conservation practices in the cellar. Please check all that apply. Final result is the sum of answers	
planning, monitoring, objectives and results of the water conservation; and results for the quality and source of water	10
septic tanks or wastewater treatment plants; liquid effluent for settling basins (settling pond or decant pond) or municipal systems wastewater treatment; liquid effluent from the process - discharges from effluent basins	10
rainwater use	10
grape reception operations water used; grape pressing operations water used	10
tanks, vats, hoses and pipes cleaning	10
barrel cleaning	10
bottling operations	10
laboratory	10
landscaping services	10
use of water pressure hoses in the winery	10
Training of farmers/staff on soil and water conservation	
more than once in three years	100
training once in 3 years	50
no training	0
Monitoring and managing water use: does your company monitor and manage your water usage?	
we have met specific reduction targets set during this reporting period	100

we regularly monitor and record emissions and have set science-based targets necessary to achieve sustainable usage linked to our local watershed	75
we monitor and record water usage and have set specific reduction targets relative to previous performance (e.g. a 5% reduction of water usage from baseline year)	50
we regularly monitor and record water usage but have not set any reduction targets	25
we do not currently monitor and record water usage	0
Water conservation practices: what water conservation methods have been implemented at the majority of your corporate offices or plant facilities? Please check all that apply. final result is the sum of answers	
low-flow faucets, taps, toilets, urinals, or showerheads	20
grey-water usage for irrigation	20
low-volume irrigation	20
harvest rainwater	20
other - please describe	20
none of the above	0
n/a - our company has a virtual office	0
Compliance with local wastewater discharge regulations and sustainability standards. Please score all that apply 100 points. Score 0 points if the answer is negative or unknown (data not available). If n/a do not answer.	
Did you get permission from your water company before you allow trade effluent such as waste chemicals, detergents, cooling or cleaning water to enter the sewerage system?	
Do you store waste safely and securely, make sure it is treated appropriately, ensure it is collected by an authorised organisation (such as your local authority or a licensed private waste contractor) and complete a waste transfer note or consignment note when waste is handed over.	
Do you ensure that any waste you produce as a result of your business operations is stored safely and securely, treated appropriately and collected for disposal or recycling by an organisation authorised to do so (such as your local authority or a licensed private waste contractor)?	
Do you consider the environmental risks for every hazardous substance you store, use, produce or dispose of at work? You must ensure you control any potential risks and comply with legislation when storing goods and materials.	
Do you follow specific environmental rules that cover potentially dangerous substances? Every business needs to think about the risks to people or the environment posed by chemicals or substances classified as hazardous to health under the chemicals (hazard information and packaging for supply) regulations (chip).	
If you manufacture, use, import or recover from waste materials any chemicals, you may have to comply with the registration, evaluation and authorisation of chemicals (reach) regulations. Businesses manufacturing, recovering or importing any chemicals over 1 tonne per year must ensure those chemicals have been pre-registered or registered in full.	
Do you notify the relevant enforcing authority and take steps to prevent the damage if your business activities pose an imminent threat to the environment?	
If your business activities cause actual environmental damage, do you take remedial action to repair the damage?	
If you work with equipment containing ods or fluorinated gases - including air conditioning and refrigeration equipment - there are requirements that you must meet regarding: containment including prevention and repair of leaks, checking for leakages and record keeping; recovery for the purpose of recycling, reclamation or destruction; training and certification. Do you follow them?	
Do you make sure that you comply with restrictions on the storage and use of hazardous substances?	
Do you ensure that any hazardous waste your business produces is correctly classified and described, and is either disposed of or recovered at an appropriately authorised facility?	
Do you monitor your wastewater or liquid waste (effluents, liquid leftovers of phytosanitary preparations, residues polluted with chemical products, etc)?	
Monitoring toxic wastewater: which of the following describes how the company monitors hazardous and toxic wastewater? *monitoring hazardous and toxic wastewater may involve either monitoring the volume and/or the level of contamination.	
eliminated emissions of this by-product entirely	100
company monitors emissions and has met specific reduction targets during the last fiscal year	75
company monitors emissions and has specific reduction targets	50
company monitors and records emissions (no reduction targets)	25
company does not currently monitor and record emissions	0
Regarding water use, does your company practice the following within the facilities you owned or leased?	
regularly assess microbial, chemical and mineral content of water used and manage water sources appropriately	100
manage use and release of wastewater in order to preserve surrounding water sources	100
design business processes to conserve/minimize water	100
none of the above	0
Regarding water recovery, does your company have the following infrastructures within the facilities you owned or leased?	
Do you have any infrastructures to collect water form cleaning?	
Do you have any infrastructures for rain harvesting?	