Agricultural irrigation of vine crops from desalinated and brackish groundwater under an economic perspective. A case study in Siġġiewi, Malta

Aparicio, Jesus and Tenza-Abril, Antonio and Borg, Malcolm and Galea, John and Candela, Lucila

Technical University of Catalonia-UPC, University of Alicante-UA, Centre for Agriculture, Aquatics Animal Sciences, Institute of Applied Sciences, Malta College for Arts, Science Technology, Water Research Training Centre, University College, Malta College for Arts, Science Technology

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Jesus Aparicio[a,b] , Antonio J Tenza-Abril[c], Malcom Borg[d,e], John Galea[d,e],

Lucila Candela, [b*]

[a]Department of Agri-Food Engineering and Biotechnology, Technical University of Catalonia-UPC, ESAB, Av. Canal Olímpic, s/n, 08860 Castelldefels, Spain.

[b]Department of Civil and Environmental Engineering, Technical University of Catalonia-UPC, DECA, Gran Capitan s.n., 08034, Barcelona, Spain.

[c]Department of Civil Engineering, University of Alicante-UA, Ctra. San Vicente s/n., 03690, Alicante, Spain.

[d] Centre for Agriculture, Aquatics & Animal Sciences, Institute of Applied Sciences, Malta College for Arts, Science & Technology, Luqa Road, Qormi, Malta.

[e] Water Research & Training Centre, University College, Malta College for Arts, Science & Technology, Corradino Hill, Paola, Malta.

* Corresponding author.

ABSTRACT

Maltese agriculture faces great challenges due to the severe scarcity of water. Sufficient water resources, in quantity and quality, are necessary to cover the demand in the production of wine grape, one of the most important crops in Maltese agriculture. But also, economic efficiency is essential in the grape cultivation. A Cost-Benefit Analysis (CBA) is defined for Maltese vineyards in the Siġġiewi region, considering two irrigation scenarios, irrigation with groundwater or "*do-nothing*", compared with the "*use non-conventional waters*" from mixing water from a small desalination plant and groundwater. For the alternative 'mixing desalinated water with groundwater' it is possible to improve water availability and quality for vine crops, while increasing economic benefits for farmer. The results indicate a profitable project from a minimum area of 1 ha, but final benefit is highly dependent on the irrigated surface extension according to water price. Desalination, compared with other type of non-conventional water is considered the best option in this assessment with a small reverse osmosis (RO) desalination plant (120 m^3/day) for covering the irrigation needs.

1. Introduction

Water availability and demand allocation, including agriculture, depend mainly on optimal natural renewal resources exploitation, integrated use management and management policy. Water availability as a resource cannot be independently considered from water quality due to pollution or depletion induced by anthropogenic activities and possible impacts from climate change. In this sense, many countries around the world will be facing the increasing pressure of decreasing fresh water supplies and that fresh water resources will become insufficient to satisfy water needs for a number of goods and services. Demands for water, energy and food production are estimated to increase by 40%, 50% and 35% respectively by 2030 (US NIC, 2012; Endo *et al.*, 2015). Water issues have been commonly discussed in the literature in terms of availability, use and reuse (including agriculture), demand, consumption, quality, management, etc. (UNECE, 2011; Gleeson *et al*. 2012; WWAP, 2012; Panagopoulos, 2014; Candela *et al.*, 2016). In the last 20 years, papers on issues concerning global change and water have been published (Olesen and Bindi, 2002; Giorgi and Lionello, 2008; Green, 2016; Di Matteo *et al*., 2017; Aslam *et al*., 2018). A detailed review of the numerous contributions is beyond of the scope of this research.

To achieve water management and planning objectives, countries usually apply two types of instruments, namely regulatory and economic. Economic instruments use market principles to achieve policy objectives involving the assessment of production and distribution costs and possibly economic and environmental value; shift in economic factors may have an effect on water use and the most affected sector is the water dependence of agricultural economy. Since agriculture represents the largest consumer, pricing is part of the water-agriculture nexus policy aiming at farm income protection based on subsidies. As regards groundwater irrigation in many Mediterranean areas, the

economic situation is different. In fact, most farmers who use groundwater for irrigation pay practically the full cost of maintenance and operation waterworks, leading to systems that are more efficient. Identifying tradeoffs and synergies are key components of the water-energy-food nexus-thinking research for sustainable development (WEF, 2011). For improving the water-food nexus efficiency, economic approaches along with technical/governance activities, are necessary for project design and implementation. Economic research activities addressing water management with agricultural management benefits projects need to be developed and conducted to analyze and understand inter-relationships and tradeoffs among resources.

From an economic perspective, hydrologic-economic models have been used from different authors to assess extraction costs and discharge willingness to pay for groundwater use including wetlands and recreation (Loomis, 2002; Burnett e*t al*., 2017; Aparicio et al., 2018), saltmarshes (Luisetti *et al*, 2014) or for agricultural production (Sales *et al*., 2017), among other applications. To our knowledge, studies on the economic importance of groundwater salinity and its effects on agricultural production considering small desalination plants have not been reported in the literature.

To demonstrate projects economic feasibility certain indicators are applied, among them the cost-benefit ratio is commonly used (Birol *et al*., 2006). A cost-benefit analysis (CBA) is a relatively simple and widely used technique that assesses how a particular market or economy at a specific site may be changed by new policies and practices (Layard, 1994; Maliva, 2014). According to CBA, a project should be only accepted if the benefits exceed any incurred costs. While different management options will yield to different net

benefits, the option with the highest value is the preferred. The application of CBA for the evaluation of projects related to water use is acquiring particular importance, even if values for water resources are not straightforward to estimate. Examples of this growing interest, mainly for water use and reuse projects setting a different net benefit value model for cost–benefit evaluation, are found in Godfrey *et al.* (2009), Seguí *et al.* (2009), Chen and Wang (2009) and Molinos-Senante *et al.* (2010) among other authors.

A good example of water increasing demand and low average precipitation with great annual and inter-annual variation is the Mediterranean region. Particularly in islands where groundwater constitutes the main water supply resource and is of crucial importance for agricultural food production, crops and livestock. Vulnerable aquifers are frequently located in zones of high demand such as coastal areas leading to water level drawdown producing seawater intrusion and man-made pollution making water resources management very challenging. Agricultural research about viticulture in the Maltese islands has been limited to irrigation needs or management principally (*business as usual*). Studies on economic costs and benefits of grape cultivation for vine production and its economic profitability are lacking.

This study is aimed to give a better understanding of the current local CBA related to Maltese vineyards in the Siġġiewi region. CBA was used herein to assess the *ex-ante* economic suitability (water quality improvement for irrigation previous to project definition and implementation) of managing alternatives to address the water-agriculture nexus. The research establishes two irrigation scenarios for the CBA analysis, the "*do-nothing*" option based on current irrigation with saline groundwater and compared to the "*use non-conventional waters*" from mixing water from a small desalination plant and

groundwater. The main objective is to assess the farmer costs and benefits from irrigating 1 ha of vineyard under the two management systems. A second objective is a sensitivity analysis of irrigation water cost (mixed water) considering five different irrigation surfaces extension.

2. Study Area

2.1. The Maltese Islands. Siġġiewi study site

The Maltese Archipelago consists of three inhabited islands, Malta, Gozo, and Comino, and some other uninhabited much smaller islands, which in all have a total surface area of 316 km^2 and a total population of about 450,000 (Fig. 1). Siġġiewi, located in South Western Malta (Fig. 1), is the third largest council in Malta and has about 9,000 inhabitants.

The climate of the Maltese islands is typically semi-arid Mediterranean, with hot, dry summers and mild, wet winters. The short, heavy rainstorms, which are common during the transition from the dry to the wet season result in increased runoff and erosion (Schembri, 1993; Falzon, 2013).

The geology of the Islands consists of marine sedimentary rocks, mainly limestone of Oligo-Miocene age and some minor quaternary deposits of terrestrial origin (Pedley, *et al.,* 1976; Schembri, 1993). The main stratigraphic units in order of decreasing age are: a) Lower Coralline Limestone; b) Globigerina Limestone; c) Blue Clay; d) Greensand and e) Upper Coralline Limestone. Aquifer units are those composed of limestone.

The aquifers in the study area belong to the Globigerina Limestone and Upper Coralline Limestone. Mainly unconfined, fractures are thought to play an important role in groundwater hydrodynamics; particularly within the marly middle formation, given that this formation has quite a high fracture density where exposed (Sapiano *et al*., 2013). Groundwater electrical conductivity of 2,000 – 3,000 µS/cm and chloride concentration between 400 - 600 ppm is commonly found in wells under exploitation (Falzon, 2013) because of seawater intrusion. Groundwater level ranges between 35 and 143 m.a.s.l. (Stuart *et al.* 2010).

Malta is dependent on groundwater for both public supply and agricultural irrigation as there is very limited surface water. Public supply sources include both boreholes and horizontal galleries dug into bedrock at the water table level (Sapiano *et al*., 2013). As the available resources cannot meet the current demand, over 50% of water for public supply is from seawater desalination by reverse osmose (RO). Seawater desalination began in 1983 and reached a peak during the1994/1995 period (Sapiano *et al*., 2013).

2.2. Agricultural management

Maltese agriculture faces great challenges due to the severe scarcity of land and the equally severe scarcity of water (CCA, 2010), which is aggravated by the population density and high annual tourist influxes. One of the most important crops and with a high demand is the production of wine. Viticulture is a growing area of interest and the total area under vines in the Maltese Islands is about 683 ha (MCCAA, 2013). Nowadays, farmers mostly use groundwater for irrigation, but the groundwater level decrease, seawater intrusion and quality deterioration by agrichemicals leads to the cultivation of wine grapes at greater risk in a short-term and long-term than other crops (Jones and

Webb, 2010). Therefore, in order to continue with the production of wine, it is necessary to have sufficient water resources in quantity and quality to cover the demand, and for optimum yield and quality of the grape.

The majority of the agricultural land in Malta is dryland for the cultivation of forage crops, covering around 5,552 ha (61.2% of the surface). Vineyards for wine production are the main permanent crop in 5.4% of the Islands' agricultural area (MCCAA, 2013). The quality wines produced in Malta are mostly from international varieties *(e.g. Merlot, Syrah, Cabernet Sauvignon, Cabernet Franc, Tempranillo, Sangiovese, and Grenache)* but there is also an increasing production from the two main indigenous grape varieties *(Ġellewża* and *Girgentina)*. Increasing presence of wine made from the indigenous varieties on the market of Quality Wines is a clear indication of the consumers change to wines produced from the indigenous varieties (MRRA, 2012).

Viticulture in Siġġiewi has been present for a long time; however, it was only until recently that there has been interest in scientific research related to grapevine growing. This mainly came about with the Wine Act of 2001 (CAP436, 2001). A 34% of the agricultural land is under irrigation, and it has been increasing over the years (World Bank, 2013). The most widespread source of irrigation water is from the underlying aquifers (Vella, 2001).

At the Siġġiewi study site, wine production is from both indigenous and international grape varieties. Grapevines are usually planted at distances from 1.8 m to 2 m apart in all directions, and the resulting plant density is of about 2,500 to 3,000 plants per ha for local varieties and 5,000 plants per ha for international grapes (Meekers, 2006; Falzon, 2013).

The common irrigation system is by dripping from groundwater wells mainly exploiting the Globigerina Limestone aquifer, following plant needs and accounting for 120L/vine/yr. Fertilization is carried out through mineral and organic fertilizers (NPK). The main difference between local and international vineyards management are the number of vines per hectare, the organic management in the local varieties and the training system (Alberello for local varieties and trellises for international varieties) and local vineyards are usually dryland, irrigation is only applied when needed (dry periods).

Irrigation water data shows that the aquifer presents high salinity (mainly due to chloride and nitrate presence). Salinity affects plants in many ways physiologically (growth, defoliation, toxic accumulations, etc.) and the only agronomical significant criterion for establishing salt tolerance is the commercial crop yield. This is an important fact conditioning agricultural production, as vine production yield also depends on water salinity. According to Mass and Hoffman (1977) and James *et al*. (1982), grape salinity optimum (threshold) is 1,500 μS/cm based in a literature review; for an average irrigation water salinity value of 2,700 μS/cm the expected decrease of crop yield may be 25%. In addition, vines are especially sensitive to chloride, which contributes to leaf chlorosis (Jackson, 2000).

3. Data and methods

The economic analysis developed includes two phases: the first one focuses on the cost-benefit analysis of present agricultural management (grapes) considering current groundwater salinity. The second step involved mixing non-conventional water from desalination with groundwater to decrease the salinity of water for wine irrigation and its cost-benefit analysis assessment. In this second phase, production increase by lowering

water salinity and cost of building a small RO desalination plant was considered. Desalinated water production is always from brackish groundwater pumped from the already existing wells in the area. The economic analysis is only calculated for the international grapes varieties under irrigation.

3.1. Data collection

For the economic analysis assessment, data from current research underway and other sources of information existing in the area, including data from the plot farmer, have been collected and provided by MCAST. No new data sets were generated for the study area characterization, which was based on existing information. The Siġġiewi site agricultural main land and agricultural management are presented in Table 1.

Costs related to agricultural management, water supply and management and beneficial effects (benefits) were estimated based on the information provided. The parameters, data and information needed to determine the water production costs (fixed and variable) from a small desalination plant, are based on the previous work of Aparicio *et al.* (2017) and are defined in Table 2 and 3.

3.2. Cost-benefit analysis (CBA)

The *CBA* method is based on the net profit estimation for each possible project choice. The project selection is based on the difference between revenues (the amount of money from grapes sold in this case), and the costs needed for the agricultural production, to be supported by the owner. Between the two general types of CBA analyses (*ex-ante, ex-post,* Boardman *et al.,* 1994), the *ex-ante* CBA of a simple purpose project for grape production, is considered here (therefore before irrigation project development with

mixing water). Positive externalities from wine production and commercialization are not considered in this economic analysis.

The CBA concept is that a project should be done only if the benefits exceed the costs. For this purpose, all benefits are compared with their costs by using a common economic analyses methodology (Eq. 1).

$$NP = TI - IC \qquad (1)$$

Where *NP* is the net profit (total internal benefit); The *TI* is the total income, and *IC* are the internal costs. For the Siġġiewi case study, the total internal benefit is grapes sales benefit or profit from agricultural production, while internal costs include: investment cost, annual volume of applied water and operational and maintenance costs (summarized in Table 3).

When conducting cost-benefit analysis on a project, a more accurate result is obtained by converting all future costs and benefits to their present values. The Net Present Value (*NPV)* is a measure of whether a project is profitable or not during the project economic horizon (life span): a negative value implies non-feasibility. The NPV criterion, given in Eq. 2, is the principal investment project evaluation criterion and is one of the most important tools applied in water project analyses.

$$NPV = \sum_{t-1}^{T} \frac{NP_t}{(1+r)^t} \qquad (2)$$

where NP_t is the net profit at year t; t is the relevant year; r is the discount rate or interest rate paid for using borrowed funds and T is the project lifespan. The rate at which benefits or costs are discounted is known as the discount rate and refers to a common measure representing the comparison of costs and benefits to occur at different time period (benefits and costs vary from year to year). The applied discount rate was 1.8% per year (OECD, 2018) for this type of projects; the considered amortization period is 10 years (Ross, *et al*. 2017).

For the CBA analysis, the alternative *"use non-conventional water from desalination for irrigation''* was compared with the *"do-nothing"* option, which implies vineyards irrigation only with local groundwater and current salinity. For the *"use non-conventional water''* option takes into account the recovery of the 25% lost production or damage caused (Kaenchan *et al*., 2018) from bad quality of groundwater irrigation (Mass and Hoffman, 1977; James *et al*., 1982; Jackson, 2000), along with the investment that would be needed to irrigate by mixing groundwater with water from a small desalination plant. For the '*do-nothing*' option, groundwater salinity increase along time is also expected leading to agricultural production losses (Itsubo and Ina, 2014) as a result of seawater intrusion by wells exploitation. Therefore, a decrease of the yield and brix levels of vineyard could be also taken into account jointly with a significant loss of income.

The Internal Rate of Return (*IRR*), an investment efficiency indicator and a measure of the comparison of the two alternatives is also calculated. Generally, the higher a project's internal rate of return, the more desirable it is to undertake as it refers to the profit rate which the owner receives. The project (groundwater *vs* non-conventional water irrigation) with the highest IRR is considered the best option.

The *IRR* calculation relies on the same formula as *NPV* does by setting it to 0 (Eq 3).

$$NPV = \sum_{t-1}^{T} \frac{NB_t}{(1+IRR)^t} + NB_0 = 0 \qquad (3)$$

where NB_0 is the initial investment costs, NB_t is the net cash inflow for period t, *IRR* is the internal rate of return, and t is the time period.

The CBA methodology to estimate NPV and IRR was applied to the two proposed scenarios, in order to assess project profitability according to the different costs (Eq. 1). Final cost and benefit estimation is a critical issue for project feasibility and it mainly depends on plot surface and irrigation water costs. A sensitivity analysis of the CBA results to assess the feasibility of project for 5 irrigated land surface extensions (0.5, 0.75, 1, 2 and 3 ha) was carried out. The final water price of irrigation water (€/m^3) was obtained by fixing plot extension and estimating the amortization and maintenance of the small desalination plant and final sale of the grapes.

3.2.1. Cost and Benefit estimation

Direct costs applicable to both irrigation scenarios refer to those needed for the agricultural management (land preparation, planting and cultivation, irrigation from well, renting equipment) needed for each grape harvest (annually) and are shown in Table 3. Land and pump acquisition or value, and well installation have not been considered as a direct cost for this analysis; this is an already existing infrastructure not specifically made for this study. Water consumption cost is obtained from considering 160 m^3/day pumping

rate, power consumption of 0.0072 kWh/m^3/m and 90 hr/year to cover the 600 m^3 demand and a well with a submersible pump at 70 meters deep.

Costs only applying for the facility investment (desalination plant building construction), operation and maintenance (supplies and replacement, energy) regarding the second scenario are shown in Table 2 (Olivieri, *et al.* 2005; Ahmad, *et al.* 2002).

Estimated final cost (€/m^3) per 1 ha of extension of cultivated grapes includes the water cost of mixing desalted water from the RO plant with the groundwater from the wells to obtain the needed salinity (average 1,500 μS/cm). The negative impact of groundwater salinity in grape production (25% production loss) is considered a negative externality and the associated cost of farmer losses is evaluated under the '*do nothing*' scenario.

For the mixing desalted water scenario to decrease water salinity *"use non-conventional waters"*, benefits are estimated. Here the benefits are defined as 'direct farmer benefits' in terms of economic revenue or the yield per hectare obtained, estimated per sale price of 0.29 €/kg (2018 data).

3. CBA results and discussion

The costs of agricultural management, production from the international varieties for both scenarios at the Siġġiewi case study can be found in table 3. For the vineyard plot characteristics, the reader is referred to Table 1.

3.1. Actual total cost and benefit for a vineyard cultivation "do-nothing option"

For 2018 and a baseline estimation of 1 ha of irrigated land, direct costs are presented in Table 3. The benefits (Eq 1) of Table 4 are obtained from gross production (kg/ha) and the average price of 0.9 €/kg (2018 data). It is assumed that the cultivated plot was under full production.

With regard to the obtained *NPV* (Eq. 2) and *IRR* (Eq. 3) the project is profitable, considering that it has a positive NPV (€ 8,148.95) and an IRR of 6.4%.

3.2. "Use non-conventional water from desalination" NPV and IRR

To obtain the adequate salinity for grape irrigation and avoid further production loses, desalinated water is mixed with groundwater from the same well. According to Mass and Hoffman (1977), James *et al*. (1982) and Jackson (2000), the optimum irrigation water quality for the vineyard is around 1,500 (μS/cm). Hence, to reach this quality, 50% of the water from RO must be mixed with 50% of groundwater.

In this scenario, desalinated water is produced from a RO small plant (120 m^3/day) treating groundwater from the existing well. In this option, the final price of groundwater for irrigation is previously obtained to get the final mixing price. Calculations consider that the plant is under operation 360 days/year. The final cost of desalinated water, after considering all the parameters are in Table 5.

For the investment costs the plant cost is 25,000 € (without VAT) and the applied depreciation rate was 4% for a 15-year life span, a common value for such type of projects (Aparicio *et al,*. 2017).

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The next step is to estimate the minimum surface area under irrigation still being profitable, considering a desalination plant of these dimensions and needed water quality for maximum production (Table 6). The different *NPV* and *IRR* calculations are based on the idea that a small plant must be fully operational and not only to supply the water demand of 1 ha. This analysis takes into consideration 25% of production increase (benefits) that would be gained by irrigating with water of optimum quality.

From the *NPV* and *IRR* sensitivity analysis (Table 6) after considering different water costs and land irrigated surfaces (ha), a wide range of surface areas are possible. Positive values of both parameters (project feasibility) start from 1 ha cultivated area, however, the final price of mixing water is € 9.08. Irrigating a higher areal extension (3 ha) by sharing the water with other farmers appears to be the best option.

4. Conclusions

Water salinity is an important factor for agricultural crop production and the associated economic output. As quality degradation maybe evident for a long-time, search for alternative sources of water supply through technical-projects solutions are generally undertaken in private business. The risk associated with the development of an inadequate water-agriculture project may involve a heavy economic burden in the case of failure to achieve the intended results. However, economic impact studies have not been carried out to assess the sustainability of such measures. Economic feasibility of a project involves the assessment of most suitable solution based 'on balance' by considering full cost estimation and benefits for each alternative and avoiding the scenario *business-as usual.*

This study presents the interest of coupling agricultural-groundwater management (*ex-ante*) cost-benefit analysis for the alternative of mixing desalinating water and groundwater to improve water availability for crops and vine harvest while increasing economic benefits. The output indicates that the project, based in an already existing agricultural land under vine production, is highly profitable from a minimum area of 1 ha; but the final benefit is highly dependent on the irrigated surface extension. For the calculation of the benefits, only the direct sale of the grapes gross production was taken into account. It needs to be noticed that new irrigation developments have necessarily to consider the incurred costs of a well drilling, pump purchase, etc., which will finally increase the irrigation water price. A comprehensive economic analysis would also consider the economic benefits of the final product (wine production); therefore, the farmer benefits would be higher.

Compared with other types of non-conventional water (e.g. treated wastewater) desalination was considered the best option in this assessment. As vineyard requires a low amount of irrigation water, the small RO desalination plants available in the market (120 m^3/day) could cover the required quality needs at not such high cost. Considering that plants of 120 m^3/day production are easy to handle and do not require very specialized knowledge, farmers can run the utility with minimum technical requirements. Other short-term investments linked to water storage, adjustments and transfers appear to be costly and time-consuming for implementation. Brine discharge, elimination of waste, environmental pollution etc., not considered in the analysis, could also directly affect final NPV estimation increasing final costs and consequently decreasing benefits. Effects on quality and quantity of groundwater by climate change (seawater intrusion or water shortage) and the excessive use of nitrogenous fertilizers in agricultural management may

also require forecasting future climate, from ICCP scenarios, which is not a straightforward process.

The methodological framework presents a brief overview of an *ex-ante* economic valuation technique application for ensuring farmers profitability while closing the water-agriculture circular economy concept. Other advantage is it provides strategic information about the main choices at an early stage, when the possibility to influence the course of an undertaking is greatest. The approach constitutes an interesting method for water-agriculture projects economic feasibility assessment applicable in areas with similar or different crop cultivation and irrigation demand provided that economic information is available or can be estimated.

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Table and figure captions

Fig. 1. Location of Maltese islands and the Siġġiewi study area

Table 1. Main characteristics of vineyard plot at Siġġiewi

Table 2. Breakdown of fixed and variable costs for a RO small desalination plant

Table 3. Cost estimation per harvest at Siġġiewi (1ha)

Table 4. Gross production of a 1ha vineyard plot (2018 data).

Table 5. Cost of desalinated groundwater from a RO small desalination plant

Table 6. Estimation of NPV and IRR for different irrigation land surfaces with the appropriate water salinity

Table 1

	Siġġiewi study area
Type of crop	Vineyard (international varieties)
Vines per hectare	5,000
Irrigated surface (ha)	1
Production (kg/ha)	8,500 (per harvest)
Irrigation from groundwater	Existing well (Lower Coralline Limestone aquifer)
Groundwater salinity (µS/cm)	2,500-3,000
Irrigation method	Dripping
Well depth (m)	128
Irrigation dose	120 L/plant/year

Table 2

Fixed costs	
	I= Initial investment
a) Initial investment: $I = (A)$	A= Cost of the desalination plant
b) Amortization: $a = I.\ \dfrac{i.\,(1+i)^n}{i.\,(1+i)^n - 1}$	I= Investment
	n= Lifetime
	i= Interest

Variable costs	
	M= Maintenance (1% of total installed cost)
d) Operational and maintenance costs: CE	MR= Replacing membranes
	FCR= Replacing filter cartridges
$CE = M + MR + FCR + CP + E$	CP= Chemical products
	E= Energy cost (well pumping, RO process, transport)

Table 3

	Cost estimation
Land preparation (€)	500
Planting work and cultivation (€)	1,700
Harvesting (€)	500
Charge for electricity meter (€/yr)	360
Water consumption cost (€/year)	124*
Total (€)	3,184

* Costs have been estimated only based on energy consumption

Table 4

Crop	Vines per hectare	Gross production (kg/ha)	Gross income (€) Total	Net Benefit/ha (€)
International vineyard	5,000	8,500	7,650	4,867

Table 5

Fixed costs	
Cost of the desalination plant (VAT included,18%) (€)	29,500
Number of lifetime years of the investment (years)	15
Interest (%)	18
Variable costs	
Maintenance (€/m^3)	0.06
Replacing membranes (€/m^3)	0.008
Replacing filter cartridges (€/m^3)	0.0025
Chemical products (€/m^3)	0.029
Energy cost (€/kWh)	0.20
Total cost without depreciation (€/m^3)	0.29
Total cost with depreciation (€/m^3)	0.35

Table 6

Area of cultivation (ha)	Price of water (€/m^3) *	NPV (€)	IRR (%)
0.5	18.14	-8,922.91	-11.3
0.75	12.16	-1,173.78	0.9
1	9.17	6,330.27	5.4
2	4.68	37,562.82	11.7
3	3.19	68,560.27	13.6

* mix of desalinated (50%) and water from the aquifer (50%)

Highlights

- Irrigation water quality degradation from salinity may pose vineyards production at risk at long term
- Water quality improvement from mixing groundwater and desalinated may mitigate crop yield decrease
- The economic feasibility of new irrigation management option based in the cost-benefit is assessed
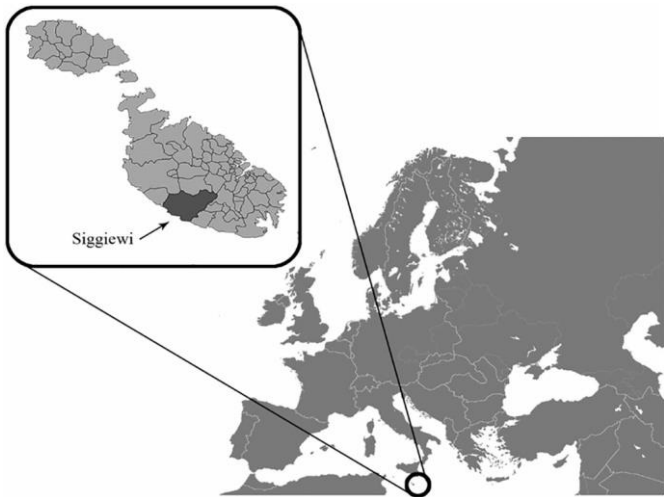- Irrigation from mixing waters is profitable for farmers from a minimum irrigation area of 1 ha

Figure 1