Contract no. **688320**

MADFORWATER

DevelopMent AnD application of integrated technological and management solutions FOR wasteWATER treatment and efficient reuse in agriculture tailored to the needs of Mediterranean African Countries

Deliverable No.	**5.2**
Deliverable Full title	**WW management strategies and water & land management strategies in agriculture**
Work Package No. and Title	**WP5 - Strategies and economic instruments for basin-scale water resources management**
Lead beneficiary (extended name and acronym)	**Universidad Politécnica de Madrid (UPM)**
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1. Introduction

In a period, where many areas worldwide are experiencing droughts and water stress, particularly in the Middle East and North African (MENA) region (figure 1) with continuously decreasing ground water level, water reuse has received growing attention (World Resources Institute 2019). Subsequently there is need for technologies and strategies that can foster the implementation of most adapted technologies and solutions. A main incentive for water reclamation[1] is the use of treated wastewater as a water resource for beneficial purposes, because it can partly substitute the abstraction of fresh surface or groundwater. A sub-incentive is that wastewater is not discharged to receiving environments, thus reducing pollution of water bodies.

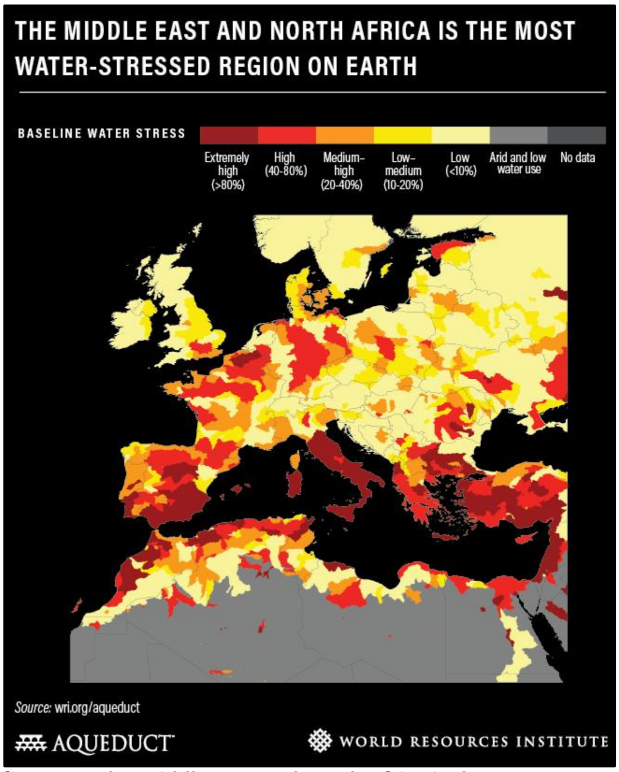


figure 1: The Middle East and North Africa is the most water-stressed region on earth. (World Resources Institute 2019)

*"**Twelve out of the 17 most water-stressed countries are in the Middle East and North Africa** (MENA). The region is hot and dry, so water supply is low to begin with, but growing demands have pushed countries further into extreme stress. Climate change is set to complicate matters further: The World Bank found that this region has the **greatest expected economic losses from climate-related water scarcity**, estimated at 6-14% of GDP by 2050. Yet there are untapped opportunities to boost water security in MENA. **About 82% of the region's wastewater is not reused**; harnessing this resource would generate a new source of clean water."*
(World Resources Institute 2019)

The general objective of the MADFORWATER project is to develop integrated technological and management solutions to boost wastewater treatment and treated wastewater efficient reuse for irrigation in selected hydrological basins in Egypt, Morocco and Tunisia. In particular, Work Package (WP) 5 '' Strategies and economic instruments for basin-scale water resources management'' aims to develop strategies for wastewater management, water reuse and

[1] Water or wastewater reclamation is the process of treating wastewater to turn it into water that can be used for beneficial purposes. Water reuse refers to the beneficial use of reclaimed water (the 'fit-for-purpose' concept)(WWDAP (United Nations World Water Assessment Programme) 2017).

water & land management in agriculture, tailored to the three studied basins. This WP will make use of two decision support tools (DSTs) to support the development of strategies and economic instruments for wastewater management and water & land management in agriculture. In this deliverable 5.2, the wastewater management strategies and the strategies for water management in agriculture are developed separately. The proposed two types of strategies will then be combined into basin-scale integrated water & land management strategies in the upcoming deliverable 6.1.

This deliverable is organized as follows: in chapter 2, the elaboration of wastewater management strategies for the three selected basins. In this chapter, we aim to develop an assessment for water reclamation and reuse and establish exemplary basin-scale strategies that include economic instruments and other measures to foster implementation. This assessment consists of three objectives, namely A) applying a decision-support tool (DST) for water reclamation potential for municipal wastewater, B) applying a DST for simulating and estimating lifecycle costs of project-related technologies for water reclamation, and C) assessing the national-level conditions for water reuse with a multi-criteria decision analysis (MCA) to identify drivers and barriers. This MCA consists of six thematic subjects, namely policy and institution, economy, society, water management, legislation and environment. In this research, wastewater reclamation is defined as cleaning of wastewater to a purity that can be used for specific purposes. Wastewater reuse is defined as beneficial use of treated wastewater (Asano, Burton, and Leverenz 2007).

This analysis was applied to three countries in Middle East and North Africa (MENA), which are Egypt, Tunisia, and Morocco. Safeguarding water security in these countries is challenging and each country faces specific water management concerns.

Egypt has been suffering from severe water scarcity in recent years. Renewable freshwater resources include only 20 cubic meters per person per year. As a result, the country relies heavily on the Nile River for its main source of water. Egypt is already below the United Nations' water poverty threshold, and by 2025 the UN predicts, it will be approaching a state of "absolute water crisis". (Eco Mena 2017; The Guardian 2015).

Tunisia's water resources are characterized by scarcity and pronounced seasonal and yearly variations. Furthermore, the country is subject to periodic droughts of various lengths. The most common drought years have rainfall deficits ranging from 30% to 50%. Over the last decade, Tunisia has achieved considerable success in expanding access to both water and sanitation services, but challenges remain (Ameur 2007; World Bank 2014a).

Morocco is among the 45 countries facing water scarcity. It is confronted with dwindling groundwater reserves and a strong dependence on rain-fed agriculture. Cultivable land is compromised, because of water shortages and soil erosion (Morocco World News 2017; USAID 2017; Espace Associatif 2012). To overcome this problem, several laws and regulations were adapted to improve the availability and quality of water resources (Choukr-allah et al. 2017).

Chapter 3 is devoted to the elaboration of sustainable water and land management strategies in agriculture for the three selected basins. The proposed strategies take into account the multifaceted perspective of the water and agricultural sectors considering technological, economic, social, environmental, institutional, and governance aspects. In addition, they take into account the increased amount of water obtained from improved water reuse and the implementation of efficient irrigation technologies. In this chapter, three scenarios characterized by different inputs are considered; the water availability scenario considering

an increase in water availability obtained from treated wastewater reuse as well as the decrease in fertilizer requirement (due to high levels of organic matter in treated WW), the technology scenario considering the MADFORWATER new irrigation technology and the policy scenario by applying different economic instruments for water management such as water pricing, water quotas, subsidies, taxes, etc. The results of these scenarios are compared with the baseline scenario.
Concluding remarks are finally presented in chapter 4.

2. Strategies and economic instruments for WW management (Task 5.2: FHNW)

2.1. Methodology: Development of a DST for the establishment of WW management strategies

2.1.1. Local adaptation of a decision support tool for water reclamation

The assessment presented in this deliverable is based on an open access pre-feasibility DST for water reuse (Oertlé et al. 2019). The DST's purpose is to identify technology options that can treat wastewater to the desired quality for several representative case studies. The user has to provide information about the wastewater to be reclaimed (i.e. quality parameters and quantity), the desired reclaimed water quality (i.e. from a set of national regulations and international guidelines), and local cost information. The DST automatically proposes top ranking technology options from a database of benchmark treatment trains (series of unit processes) based on lifecycle treatment costs or based on a weighting profile defined by the user. It currently encompasses 37 units processes combined into 70 benchmark treatment trains. The detailed description of the DST is presented in a dedicated publication (Oertlé et al. 2019). The DST focuses on the pre-feasibility stage and considers potential water reuse schemes in a systemic approach schematically (Figure 2). This allows determining if an identified area with potential for water reuse could lead to a feasible reclamation scheme with current resources, technologies and available information.

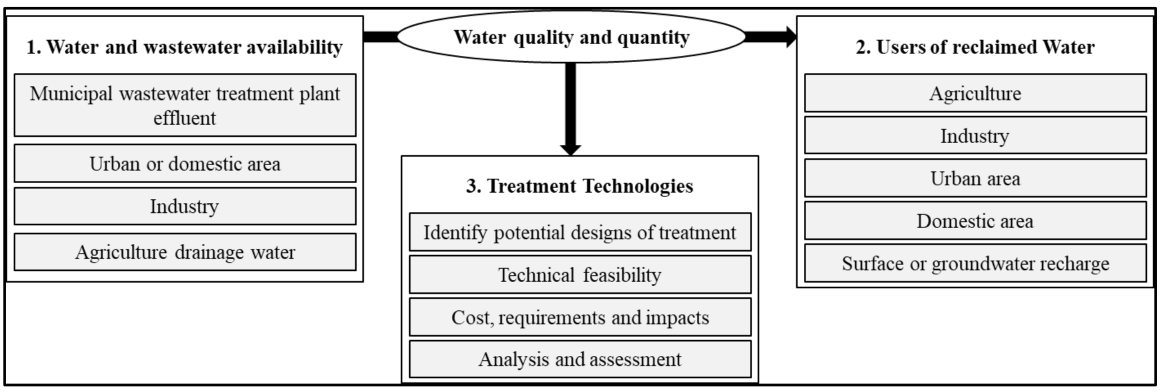


Figure 2: Water reuse for pre-feasibility in a systemic approach: (1) wastewater for reuse, (2) type of intended reuse, (3) identification and assessment of technology.

It would be too extensive to describe in details the DST in this deliverable and most of it has already been published. For more information on the content of the DST, its mode of calculation and data included, please refer to the following open-access publication and datasets:

- Publication with detailed description of the DST (Oertlé et al. 2019).
- Externally hosted supplementary file 1, Oertlé, Emmanuel. (2018, December 5). Poseidon - Decision Support Tool for Water Reuse (Microsoft Excel) and Handbook (Version 1.1.1). Zenodo. http://doi.org/10.5281/zenodo.3341573
- Externally hosted supplementary file 2, Oertlé, Emmanuel. (2018). Wastewater Treatment Unit Processes Datasets: Pollutant removal efficiencies, evaluation criteria and cost estimations (Version 1.0.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.1247434
- Externally hosted supplementary file 3, Oertlé, Emmanuel. (2018). Treatment Trains for Water Reclamation (Dataset) (Version 1.0.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.1972627
- Externally hosted supplementary file 4, Oertlé, Emmanuel. (2018). Water Quality Classes - Recommended Water Quality Based on Guideline and Typical Wastewater Qualities (Version 1.0.2) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.3341570

For this research, the DST has been adapted to the specific cases of Egypt, Morocco, and Tunisia, by including data and information in the tool. Data were collected in a literature research on typical wastewater qualities, national regulations on water quality requirements for the compliance with different types of reuse, and local cost factors (see Table 58 and Table 59). Such factors include energy cost, personal cost and discount rates (i.e., interest minus inflation rate). The whole set of collected data and the resulting DST is presented in supplementary materials of this deliverable and has been uploaded to an open access repository (Oertlé 2018a).

To conduct a generic assessment for the three countries, typical wastewater quality classes in the Mediterranean and African Countries (MAC) have been established based on collected local data and complemented with values from literature (Asano, Burton, and Leverenz 2007) (Table 1). Specific contaminants from industrial wastewaters are not included in Table 1 (i.e. polyphenols, fungicides, dyes) but should be considered when designing treatment trains treating industrial wastewater. Furthermore, national regulations for wastewater reuse and irrigation are considered together with ISO guidelines, as the achievable water quality targets for the reclaimed water to be compliant.

Table 1: Typical wastewater qualities and guidelines for wastewater reuse ('-'stands for 'no data available' or 'not defined')

Water quality classes	Turbidity [NTU]	Total Suspended Solids (TSS) [mg/L]	Biological Oxygen Demand (BOD) [mg/L]	Chemical Oxygen Demand (COD) [mg/L]	Fecal Coliforms (FC) [CFU/100ml]	Total Coliforms (TC) [CFU/100ml]
Typical wastewater quality in the Mediterranean and African Countries (MAC) (Asano et al. 2007b; Oertlé and Gauer 2018; Frascari 2019)						
Municipal wastewater quality	100	400	400	1,000	10,000	5,600,000
Municipal wastewater treatment plant secondary effluent	0.5	25	31	56	-	10,000
Olive mill wastewater	-	12,000	40,000	60,000	1	1
Fruit and vegetable packaging wastewater	-	250	350	700	8,000,000	30,000,000
Drainage canal water	-	80	40	72	178,000	-
Textile wastewater	334	104	69	356	-	-
BS ISO 16075-2:2015 Guidelines for treated wastewater use for irrigation projects (ISO 16075-2 2015)						
Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	5	10	10	-	-	100
Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	-	25	20	-	-	1,000
Cat. C: Agricultural irrigation of non-food crops	-	50	35	-	-	10,000
Cat. D: Restricted irrigation of industrial and seeded crops	-	140	100	-	-	-
Cat. E: Restricted irrigation of industrial and seeded crops	-	-	35	-	-	-
Egyptian Guidelines for wastewater reuse (Elbana et al. 2014; El Bouraie et al. 2011)						
Level A: Landscape irrigation in urban areas	-	20	20	-	-	1,000
Level B: Agriculture purposes in desert areas	-	50	60	-	-	5,000
Level C: Agriculture purposes in desert areas	-	250	400	-	-	-
Law 48/1982: Protection of the River Nile and water ways	-	-	6	10	-	-
Moroccan water irrigation regulation (S.E.E.E. 2007)						

Water quality classes	Turbidity [NTU]	Total Suspended Solids (TSS) [mg/L]	Biological Oxygen Demand (BOD) [mg/L]	Chemical Oxygen Demand (COD) [mg/L]	Fecal Coliforms (FC) [CFU/100ml]	Total Coliforms (TC) [CFU/100ml]
Cat A: Irrigation of crops to be eaten raw	-	100	-	-	1,000	-
Cat B & C: Irrigation of other crops	-	100	-	-	-	-
Tunisian guidelines for wastewater reuse (WHO 2006; Food and Agricultural Organisation of the United Nations 2013)						
NT 106.03 standard: Irrigation	-	30	30	90	-	-
Norm 106.03 revised, Cat I: Agriculture use	-	-	-	-	-	-
Norm 106.03 revised, Cat II: Golf places, urban parcs, green zones	-	-	-	-	1,000	-
Norm 106.03 revised, Cat III: Infiltration of groundwater for agricultural use	5	-	20	125	1,000	-

2.1.2. Definition of representative case studies

The application of the DST to the Egyptian, Moroccan and Tunisian contexts follows two main approaches, A and B (see Table 2). The first approach (A) consists of identifying treatment trains that could treat typical municipal wastewater and secondary effluent of municipal wastewater treatment plants to a quality level that complies with ISO guidelines and with national regulations on treated wastewater reuse. The identified treatment trains are then ranked based on cost of treatment and the defined weighting profile (see Table 60 and Table 61). The second approach (B) consists of simulating treatment trains originating from the MADFORWATER project (www.madforwater.eu) and calculating corresponding lifecycle treatment costs for different flow rates in the three target countries. The DST was applied to every defined case study (Figure 3).

Table 2: Case studies considered for the assessments A and B

A. Municipal wastewater		**Purpose: identify treatment trains compliant with international and national regulations**
Typical municipal wastewater quality (MWW)	10,000 [m³/d]	ISO Guidelines (16075-2:2015) Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw, Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops, and Cat. C: Agricultural irrigation of non-food crops. Egyptian, Moroccan, and Tunisian regulations for wastewater reuse.
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)	10,000 [m³/d]	
B. Specific wastewater and corresponding treatment trains (TT)		**Purpose: calculate lifecycle treatment costs for a selected series of unit processes**
Drainage canal water (DCW-TT)	1,000 [m³/d]	Anaerobic stabilization ponds, constructed wetland
Fruit and vegetable packaging plant (FVPWW-TT)	200 [m³/d]	Activated sludge, flocculation, activated carbon, ultraviolet disinfection
Municipal wastewater (MWW-TT)	10,000 [m³/d]	Trickling filter with secondary sedimentation, sedimentation without coagulant, constructed wetland, chlorine dioxide, equalization basin
Olive mill wastewater (OMW-TT)	100 [m³/d]	Microfiltration, ion exchange
Textile wastewater (TWW-TT)	200 [m³/d]	Flocculation, sedimentation without coagulant, low loaded activated sludge with denitrification and secondary sedimentation

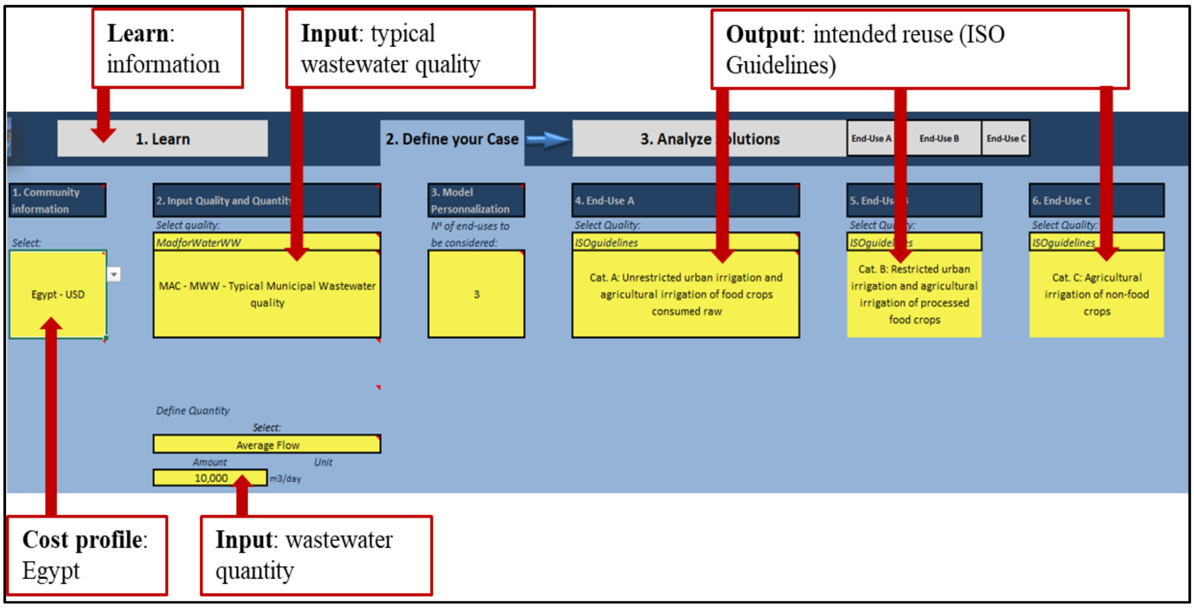


Figure 3: Application of the decision support tool (i.e. Poseidon)

2.1.3. Assessment of national-level conditions for water reuse

This MCA consists of six thematic subjects, namely economy, water management, policy and institution, legislation and environment. Each thematic subject is described by two to four key questions. These in turn are underpinned by one quantitative or semi-quantitative indicator (Table 3 for overview; Table 55 for details in supplementary materials). Collectively, these indicators provide an indicative general understanding of the current situation of water reuse in Egypt, Tunisia, and Morocco and are selected on the basis of existing indicators, which were scanned from major water reuse studies and recognised databases (Esteve et al. 2017; Snethlage et al. 2018; FAO - UN Food and Agriculture Organisation 2016). The analysis was also applied to Australia. The reason for integrating Australia is its function as a benchmark country with well-established water reuse practices (Asian Development Bank 2017).

To develop a hands-on DST, we developed a twofold investigation of the MCA. First a simplified statement is provided by answering 7 selected key questions that are underpinned by one quantitative or semi-quantitative indicator (highlighted in grey in Table 3). Second for an “expert” (detailed) investigation, in the DST we provide all key questions and the subsequent quantitative or semi-quantitative indicator (Table 3).

The indicator results were classified as ‘lower’ = 1, ‘moderate’ = 2, and ‘higher’ = 3 (see Table 56 in supplementary materials). For the indicator results, a linear ranking was applied if possible. This included for ‘lower’: 0 – 33.3%, ‘moderate’: >33.3 – 66.6%, and ‘higher’: 66.6 – 100% based on (BGS 2015; Oakdene Hollins 2008). The terms ‘lower’ and ‘higher’ were applied, because the connotation of these terms better describe the involved data uncertainty than the connotation of ‘low’ and ‘high’.

Four indicators were scored for the assessment of the countries Egypt, Tunisia, Morocco, and Australia in this research only. Therefore, for each of these four indicators, the maximum water reuse level was assigned as the maximal value. The minimum water reuse level was assigned to the minimal value. In between these maximum and minimum, a linear ranking of thirds was determined. This was applied to the indicators, namely: ‘Water pricing for agriculture’, ‘Financial subsidies’, ‘Percent of annual produced water volume per total population in a country', and 'Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)'. Due to lack of data, the indicator 'Social acceptance in a country towards the water reclamation for agriculture' could not be scored. We are establishing this indicator in ongoing research activities. Currently, we assumed that the indicators are equally weighted; this assumption will be tested in our future research activities.

Table 3: Description of the thematic subjects, key questions, quantitative and semi-quantitative indicators with possible data sources. The grey highlighted cells are used in the DST in the simplified investigation. N/Av stands for 'not available'.

Thematic subject (Ts)	Key question	Indicator	Unit	References
Economy (Ec)	-What is the **official financial development assistance** (gross expenditure) for water supply and sanitation?	Total official financial development assistance (gross disbursement) for water supply and sanitation for water supply and sanitation by recipient per WW production in a country and year	Euro/m³ produced wastewater	UN – SDG Indicators 6.a.1 Global Database in Esteve et al. (2017)
	-What is the level of **economic water security**?	Economic water security	N/Av (ratio of max. 20)	(Snethlage et al. 2018)
	-What is the **water pricing for agriculture**?	Water pricing for agriculture	Euro / m³	(Esteve et al. 2019; Australian Government 2019)
	-What are the **financial subsidies** for water use in agriculture?	Financial subsidies	% reduction	(Esteve et al. 2019)
Water Management (WM)	-What is the **transboundary water dependency ratio**?	Transboundary Water Bodies Dependency Ratio in the Northern African region	%	2nds Arab State of Water Report in Esteve et al. (2017)
	-What is the share of **produced volume** of industrial and municipal wastewater per total population in a country?	Share of annual produced industrial and municipal wastewater volume per total population in a country	m³/(a*inhabitants)	(FAO - UN Food and Agriculture Organisation 2016; University of Tunis El Manar 2018; Direction Générale du Génie Rural et de l'Exploitation des Eaux 2017; Commissariat Regional au Developpement Agricole Nabeul 2016)
	- What is the share of **treated to produced volume** of industrial and municipal wastewater?	Share of annual treated to produced industrial and municipal wastewater	%	2nds Arab State of Water Report in Esteve et al. (2017) (FAO - UN Food and Agriculture Organisation 2016; University of Tunis El Manar 2018; Direction Générale du Génie Rural et de l'Exploitation des Eaux 2017; Commissariat Regional au Developpement Agricole Nabeul 2016)
	-What is the share of **harvested irrigated crop area per cultivated area**?	Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)	ha	(FAO - UN Food and Agriculture Organisation 2016)
Policy and institutional (P&I)	-What is the proportion of **monitoring and reporting** systems **in comparison to other countries**?	Proportion of monitoring and reporting system between African countries reported on by country	%	(Esteve et al. 2017)
	-What is the degree of **implementation of national monitoring and reporting** system?	Degree of implementation of national monitoring and reporting system	%	(Esteve et al. 2017)

Legislation (L)	- What is the **quality of contract enforcement, property rights, and the courts** in each country?	World governance index, rule of law	%	(Kaufmann, Kraay, and Mastruzzi 2010)
	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	Compliance for food and non-food crop irrigation with reclaimed water	ranking: yes, partly, no	Own development, and (Mueller 2018), and intended stakeholder survey by Mueller et al. (2019)
Society (S) including public involvement in the decision making processes	-What is the degree of **implementation of equitable water and wastewater tariffs?**	Degree of implementation of equitable and efficient water supply and wastewater tariffs	%	2nds Arab State of Water Report in Esteve et al. (2017)
	-What share of population is using **improved sanitation services**?	Share of using improved sanitation services	%	UN – SDG Indicator Global Database SDG 6.2.1 in Esteve et al. (2017)
	-What is the **social acceptance** of a country towards water reuse for agriculture?	Social acceptance in a country towards the water reuse for agriculture	N/Av	Intended stakeholder survey by Mueller et al. (2019)
Environment (En)	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	Compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guideline	ranking: higher, moderate, lower	Own development, and (Mueller 2018), and intended stakeholder survey by Mueller et al. (2019)
	-What is the share of **the area equipped for irrigation that has become salinized**?	Percent of area equipped for irrigation that has become salinized	%	(FAO - UN Food and Agriculture Organisation 2016)

2.1.4. Resulting DST – DST for Water Reclamation beyond Technical Considerations

The two above mentioned assessments were combined into one standalone DST that allows potential users to establish water reclamation strategies at a pre-feasibility stage. The existing technological WW treatment DST (described under 3.1.1) was taken as a basis and extended by the national-level multi-criteria assessment (MCA). The underlying technological data (unit processes, treatment trains, etc.) therefore correspond to the descriptions under 2.1.1. Concerning the national-level MCA, an expert and simplified version of the results has been developed (3.1.3). The DST itself will be delivered as Deliverable 5.3 of the MADFORWATER project. In addition, it will be uploaded on an open-access repository.
The following 'Guided tour' is intended to give an overview of the combined DST from a user's perspective:

A. Guided steps:
The tool consists of 4 main steps: (1) learn, (2) input data, (3) analyse solutions, and (4) summary (Figure 4). Firstly, the user should select the country to be assessed and a corresponding currency. This information is mainly required to display the correct national-level MCA results at the end. For example, the user can select "Tunisia and Tunisian dinar" or "Tunisia and US dollar".

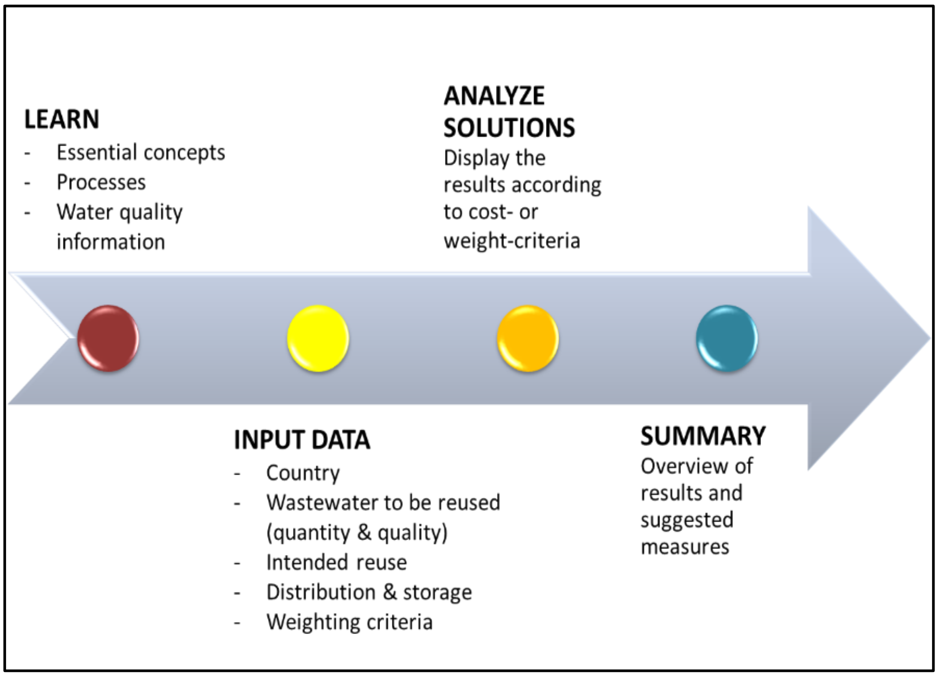


Figure 4: DST Guided Steps

B. STEP 1: Learn
The user can, depending on his existing knowledge, inform himself about the essential underlying concept and definitions, the processes and the different water qualities by

means of a list (marked yellow). For example, the user can learn about 'primary treatment' and what it means in the context of WW treatment (Figure 5).

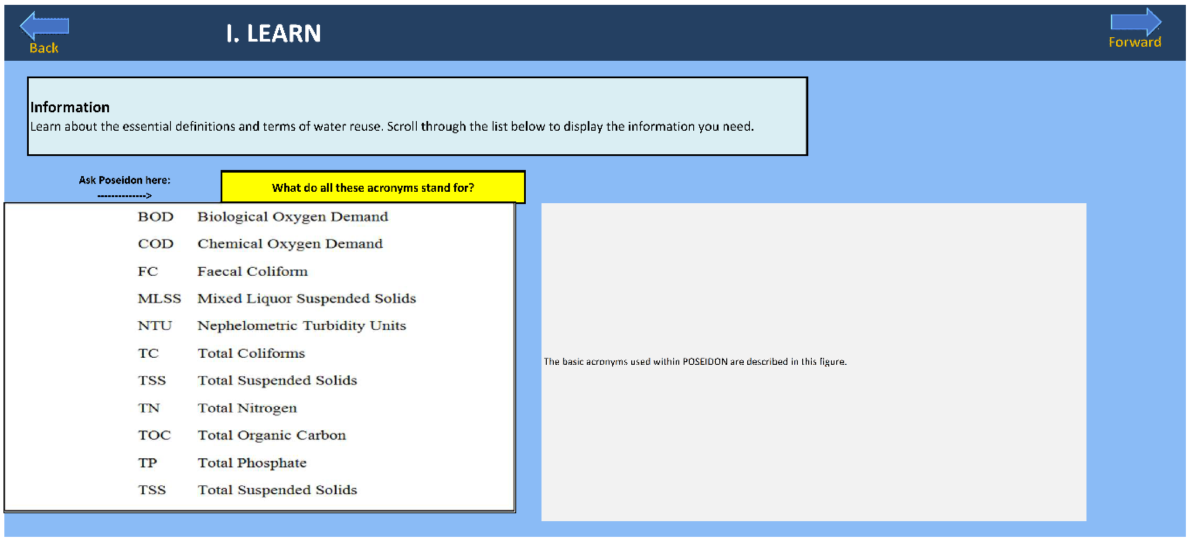


Figure 5: Learn - Essential information about the water reuse concept, underlying processes, definitions and terms.

C. STEP 2: Input Data

C.1. Water inflow quality and quantity

The user can choose between two alternatives to enter his wastewater **quality** inflow (Figure 6).

i. Either the user chooses from predefined water quality inflow data or
ii. defines his own water quality parameters.

If the user decides to use predefined water quality inflow data (defined as II.A.1), in the first step the user has to select a water quality from a given list (e.g. wastewater), and then in the second step specify the chosen water quality, also on the basis of a given list (e.g. typical untreated domestic wastewater).
However, if the user decides to enter his own water quality parameters, he can enter his own parameters accordingly in section II.A.2.

Additionally, the user must specify the inflow water **quantity.** The user can choose between three options (serviced population, average flow or peak flow). For example, the user selects 'serviced population' as the unit and enters'10,000 people' as the amount.

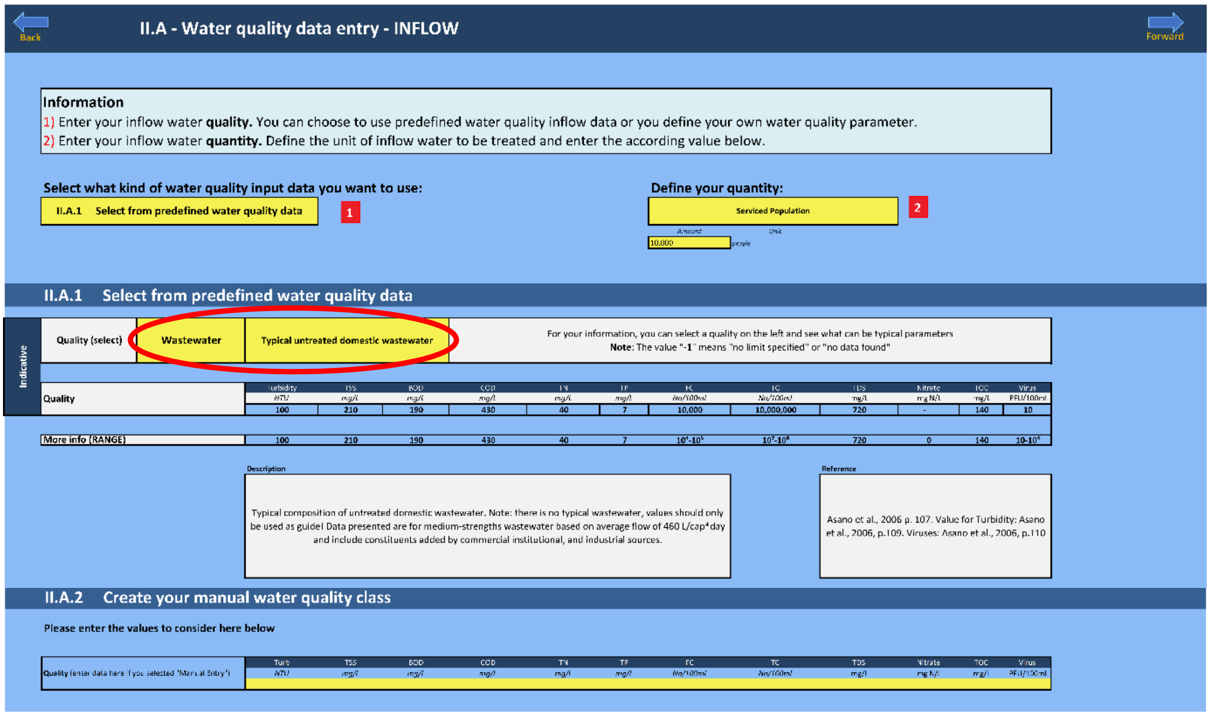


Figure 6: Water quality & quantity entry

The user must specify the desired water outflow quality according to the national regulation standards. The water quality regulation or guideline chosen defined the required water quality to be attained after water reclamation to be compliant.

Firstly, the number of end-users the user wants to supply needs to be defined in order to compare up to three different options (in case of several end-users). Secondly, the water quality and the corresponding water quality class (regulation) must be selected for each end-user. Additionally, a foreseen water tariff can be entered for each end-user.

At the lower end, the selected inflow water quality values are displayed under point three to provide a comparison between the required water quality values under point four. The comparison provides the user with an overview whether certain water quality parameter values already comply with the selected regulation standards or not. This is illustrated by color markings (red = treatment necessary; green = compliant) (Figure 7).

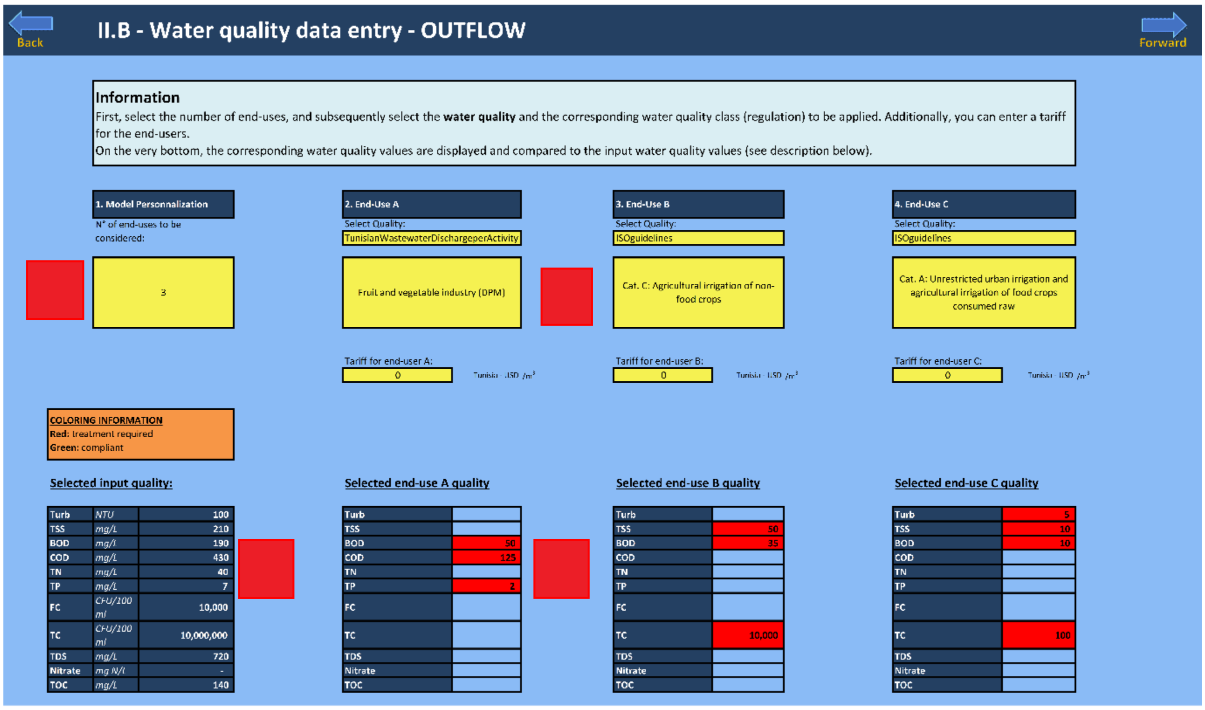


Figure 7: Water outflow quality entry

The user can enter data about distribution and storage costs (if available) or otherwise enters data about the need of storage and distribution pipelines. The distribution parameters (to the user's plant, as well as out of the plant) can be specified under point one and three. It is required to enter the type of land use where to transport wastewater is planned, the length of the pipeline and the elevation to be overcome (Figure 8).

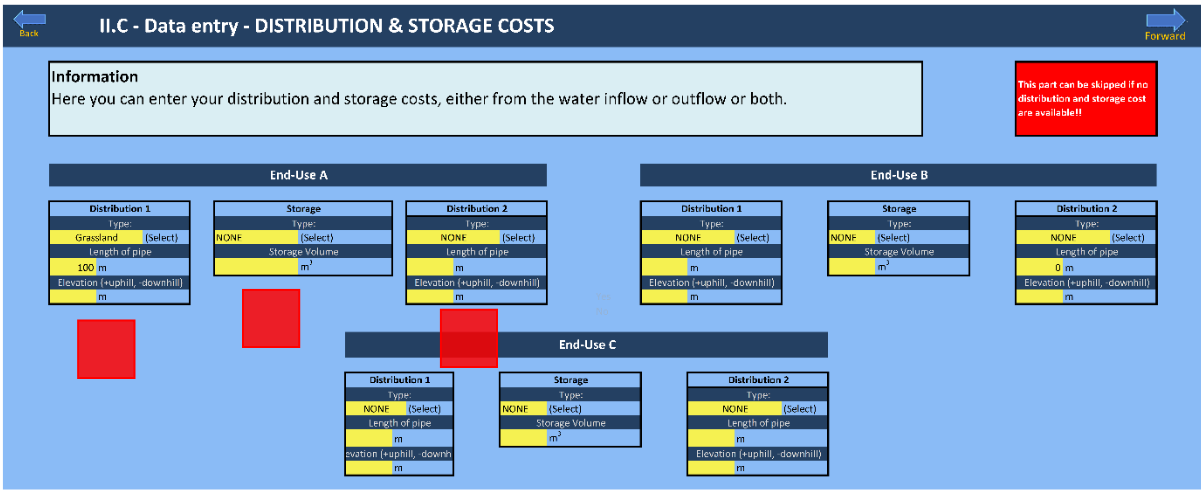


Figure 8: Distribution & storage costs

C.4. Weighting the relative importance of different parameters

This step has been added in order to include qualitative options adapted to local environmental, economic, and social conditions. The user can either choose to weight each parameter separately or select from predefined weighting profiles, for instance the 'only power demand'-profile. This 'Evaluation Profile' intends to provide the user with the possibility to evaluate WW treatment strategies not only based on meeting quality requirements (for further explanation, see ANALYZE SOLUTIONS). (Figure 9)

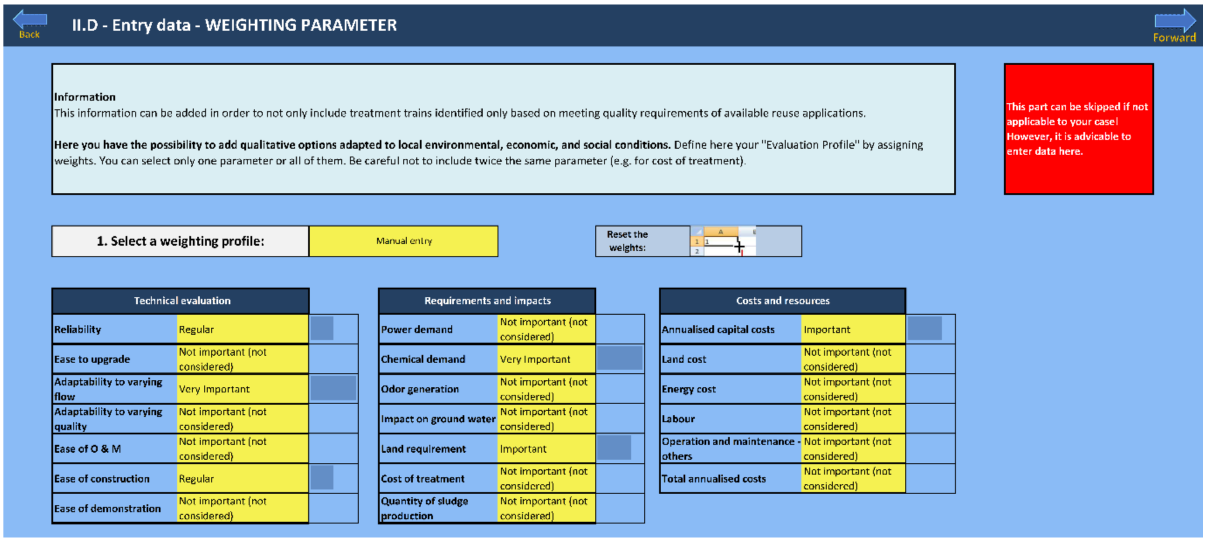


Figure 9: Weighting parameter entry

D.1. Technological results

The user can now distinguish between two criteria on the basis of which the analysis is carried out.

i. *Either the user defines the cost of the strategies as the criterion or*
ii. *the weighting profile defined by the user him-/herself*

The three top-ranking WW management options are subsequently displayed according to the criteria chosen (see Figure 10). Both the individual treatment costs and the distribution costs of the respective options can be compared. In addition, the cost-revenue value is calculated, which includes the foreseen water tariff. Furthermore, the user is provided with additional information on the treatment trains, unit processes, as well as detailed information on the cost values and calculations.

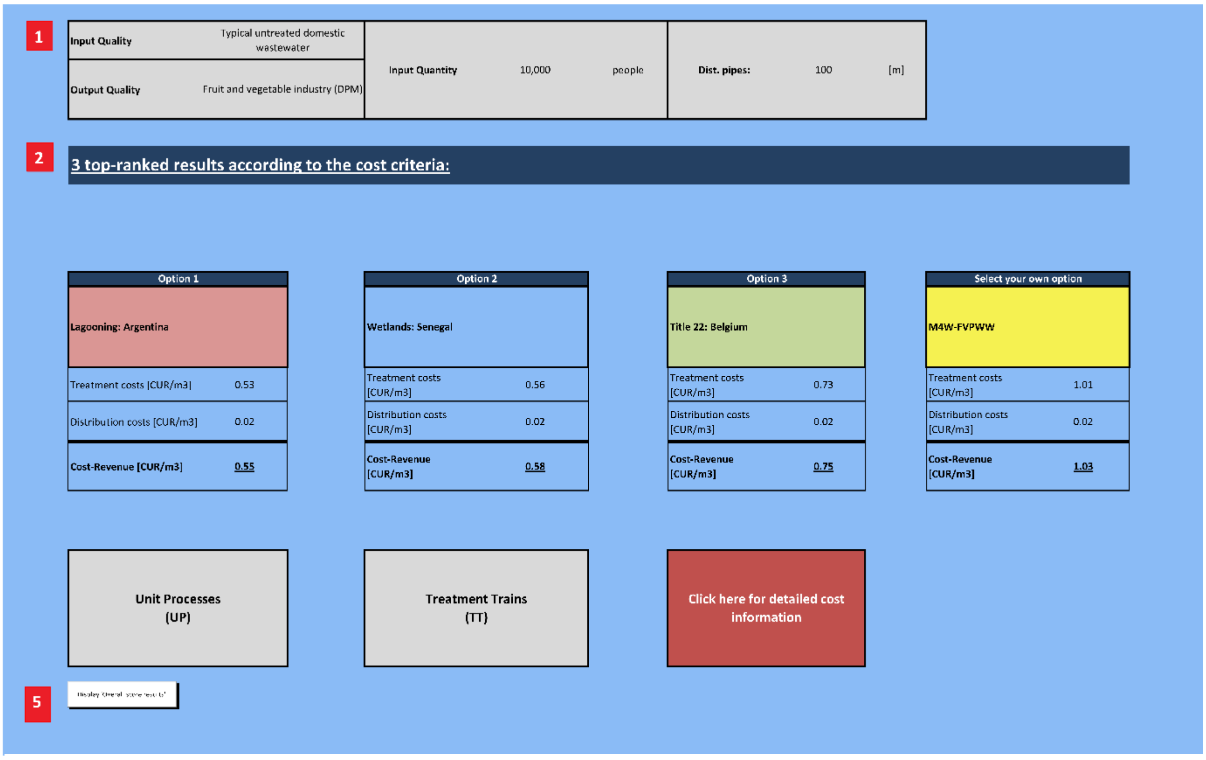


Figure 10: Technological results

D.2. Qualitative national-level assessment results

Moreover, the user must decide how to display the results of the national-level assessment. It can be chosen between a simplified or an expert view. Since the results of the national-level assessment are very detailed, a simplified view has been added (see table 3) due to the different background knowledge of the users (see Figure 11).

The numerical results were normalized to a scoring between 1 (orange; lower ranked), 2 (yellow; moderate ranked), and 3 (green; higher ranked). The detailed results have been aggregated to provide an overall statement of each thematic subject. Consequently, the average scoring result can be taken as an indicator for the thematic subject for which measures should be taken most urgently.

Figure 11: National-level MCA results

E. STEP 4: Summary

The summary at the end serves as an overview for the user. The user should select one of the top-ranked WW strategies per end-user. Consequently, the costs of the corresponding strategies are displayed and compared with the expected country-specific water tariffs (obtained from the national-level assessment). In addition, the national-level MCA results are presented again in abbreviated form and supplemented with potential measures to tackle single specific thematic subjects of water reuse. (Figure 12)

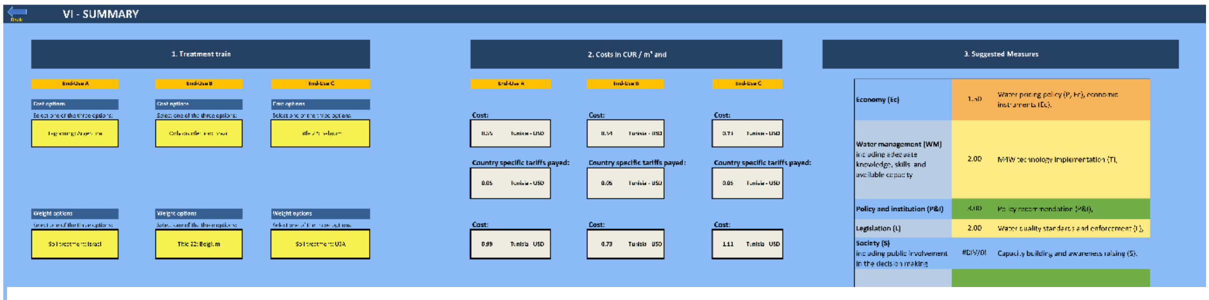


Figure 12: Summary of resulting wastewater management strategies

2.1.5. Economic instruments applied in water management in the agricultural sector

Economic instruments are used to add economic value to water in order to justify the need for the rational allocation of water as a scarce resource. There exist a variety of economic instruments that can be used in water management. In this section, we present a brief overview of the most usually applied instruments. In general, two different types of instruments can be distinguished. Firstly, the quantity-based instruments, where the quantity of water is limited and thus, if trade is permitted, a price is established through the trade market. Secondly, the price-based instruments, where the price is directly or indirectly influenced by instruments (e.g. increase through taxes or decrease through subsidies). Another not-classifiable instrument related to water management is the insurance instrument.

Table 4 gives an overview about the main types of instruments and their differences, supplemented by examples. The source of this economic instruments bases on the Deliverable 5.1 from the H2020 MADFORWATER project (MADFORWATER Project 2018).

Table 4: Economic instrument overview **(MADFORWATER Project 2018)**

Type of instrument	Examples
Price-based instruments	**P1**: Pricing/ water tariffs **P2**: Subsidies or other financial assistance (e.g. assisted loans) **P3**: Taxes
Quantity-based instruments	**Q1:** Quotas (command-and-control) **Q2:** Water markets/ water trading
Non-classified instruments	**N1:** Insurance

P1: Pricing/ water tariffs

Pricing is currently one of the most important economic tools in water management. Water prices are not usually set in market environments due to several issues (see MADFORWATER Project 2018 for further explanation) and therefore are usually subject to public intervention by means of the implementation of regulation and control from government and public administrators such as pricing schemes. Pricing schemes such as water tariffs can be distinguished in two main categories: Non-volumetric (do not depend on the actual amount consumed) and volumetric (a variable amount is charged according to the volume of water consumed). Non-volumetric pricing displays the advantage of being easy to implement, as only data about farm size, input, output, type of crop or time of use is needed. However, they do not usually provide much incentives for saving water and installing efficient equipment, as the charge does not vary with consumption. On the other hand, volumetric pricing is able to promote a better allocation of the resource, but it is more complex to manage, and it requires the installation of meters able to measure actual consumption (Dudu and Chumi 2008).

P2: Subsidies or other financial assistance (e.g. assisted loans)

Subsidies are a form of financial aid or support usually with the aim of promoting economic, environmental or social goals. Financial assistance and subsidies usually come in various ways, including: direct forms (cash grants, interest-free or low-interest loans,…) and indirect (reduced regulation, tax breaks, rent rebates…).

In the agricultural sectors, financial assistance may have different objectives, such as providing a stable income to farmers -e.g. cash transfers- (Rey et al. 2018) or promoting incentives to install efficient modern irrigation systems -e.g. subsidized loans, rebate programs- (Thivet and Fernandez 2012). However, in practice, their contribution to achieving the objectives expected from water policy is not clear and they have been found to usually harm cost recovery (Rey et al. 2018).

P3: Taxes

Water taxes are levies or charges on water use directed at achieving a specific target (environmental, economic or social goals). They are useful in the sense that they can help to address market failures by internalizing the true cost of depleting the resource, with their functioning being very similar to other charges such as prices. Some examples of taxes related to agricultural water management are groundwater abstraction charges (in which a tax is imposed on each cubic meter reflecting the cost of depleting aquifers) or effluent taxes (used to reduce point source pollution).

Q1: Quotas (command-and-control)

Quotas are based on providing farmers with the entitlement to a certain limited amount of water, which may be defined in absolute terms or according to several criteria (Van Den Berg et al. 2016). They might be useful to control the maximum demand that will be available, and they are equitable in the sense that water is allocated according to objective criteria, although they are less flexible than other methods such as water markets (Government of Canada 2005).

Q2: Water markets/ water trading

They can be defined as an institutional framework to trade water rights in a temporary or permanent way in exchange for pecuniary compensation (Rey et al. 2018). As with quotas, they offer the advantage to allow regulators to control the total amount of water that is abstracted. Moreover, in a competitive setting, markets would allow to reallocate water to its highest value use, thus promoting efficiency (Government of Canada 2005). Therefore, they are considered by some authors as a cost-efficient mechanism (Escriva-Bou, Pulido-Velazquez, and Pulido-Velazquez 2017). However, in practice water markets may end up operating in monopoly conditions (Government of Canada 2005) and sometimes local economies may be harmed (Doherty and Smith 2012). Therefore, a proper regulatory framework that stablishes clear guidelines for the design and implementation of water market has been found key for a correct functioning (Wheeler et al. 2017) and for the success of water markets.

N1: Insurance

Insurance is an economic instrument in which a person or entity (insurer) covers a potential loss of other agent (the insured) in exchange for guaranteed and relatively small payments. It is therefore a form of protection from financial and risk-contingent losses. In the case of agricultural water management, crop insurance protects for the effects of droughts, offering farmers a compensation for the loss in production. Since it has been found that water deficits during droughts usually lead to illegal abstractions (Pérez-Blanco and Gómez, 2014), crop insurance could prove a useful instrument to avoid aquifer overdraft.

2.2. Application of the DST and assessment of national-level conditions for water reuse

2.2.1. Assessment of potential for municipal wastewater reuse in agriculture

For every considered case study, treatment trains that comply with the water quality requirements of the ISO guidelines were identified. For all considered case studies, the results include the top-ranking option considering the cost (i.e., C1) and the top-ranking option considering the weighted evaluation factors (i.e., W1). Those results are a good indication of the potential for water reuse and possible treatment trains. However, this is a simplified pre-feasibility assessment with limitations, as it is only based on the parameters defined in the

DST. Additional parameters currently not considered should be included in future feasibility studies.
Nevertheless, the results show that there are available technologies that could treat typical Egyptian, Moroccan, and Tunisian municipal wastewater and secondary effluent of municipal wastewater treatment plants to fully comply with international standards. Identified options ranked according to costs have a lifecycle treatment cost ranging between 0.22-0.97 USD per cubic meter for reclaimed water. Thus, these options provide reclaimed water at an affordable cost.

Table 5: Top-ranking treatment trains based on cost (C1) and weights (W1) for treating municipal wastewater and secondary effluent to comply with ISO guidelines and lifecycle treatment costs in Egypt, Morocco and Tunisia

Ranking	Egypt [USD/m³]	Morocco [USD/m³]	Tunisia [USD/m³]
Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw			
Typical municipal wastewater quality (MWW)			
C1-'Title 22: Belgium' W1-'Only disinfection Benchmark Technology'	0.97 1.19	0.59 0.68	0.52 0.65
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
C1-'Lagooning: Australia' I W1-'Wetlands: Spain'	0.39 1.01	0.23 0.59	0.22 0.56
Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops			
Typical municipal wastewater quality (MWW)			
C1-'Wetlands: USA' W1-'Only disinfection Benchmark Technology'	0.80 1.19	0.44 0.68	0.42 0.65
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
C1-'Lagooning: Australia' I W1-'Wetlands: Spain'	0.39 1.01	0.23 0.59	0.22 0.56
Cat. C: Agricultural irrigation of non-food crops			
Typical municipal wastewater quality (MWW)			
C1-'Wetlands: USA' W1-'Wetlands: Spain'	0.80 1.01	0.44 0.59	0.42 0.56
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
C1-No treatment W1-No treatment	0.00 0.00	0.00 0.00	0.00 0.00

Identified treatment trains presented in Table 5 are based on a list of 70 treatment trains included in the DST (Oertlé 2018b). These are mostly based on typical benchmark technologies and on case studies from around the world. Results show that five treatment trains highly ranked in the assessment have a high potential for the defined case studies:

- *Title 22: Belgium*: Example from Belgium re-using water to produce cooling water for industrial purposes. A pharmaceutical company (Tienen) makes use of treated municipal wastewater for cooling water. Thereby, secondary treated effluent is ozonated for disinfection. If the amount of reclaimed wastewater is too low or temperature is too high, it is mixed with groundwater before usage. The wastewater treatment plant (WWTP) consists of a low loaded activated sludge system with enhanced biological phosphorous removal (Davide Bixio, Wintgens, and Bixio 2006).

- *Only disinfection Benchmark Technology*: Many examples are available all over Europe. Conventional wastewater treatment, followed by chlorination, enabling the reuse of the treated water for irrigation under restricted conditions (Van Der Graaf et al. 2005).
- *Lagooning Australia*: Example from Australia of water reclamation for horticultural (unrestricted) irrigation. WWTP effluents are reused for horticultural irrigation. Main irrigated crops are root and salad crops, brassicas, grapes and olives (= unrestricted irrigation). Sewage is treated in the WWTP by activated sludge process. The effluents from secondary treatment are then held in shallow aeration lagoons for a minimum of 6 weeks, before passing through a dissolved air flotation and dual media filtration process at the water reclamation plant. Here, the effluents discharge to balancing storage via a chlorinator before being pumped into the pipeline for horticultural irrigation distribution (Davide Bixio, Wintgens, and Bixio 2006).
- *Wetlands Spain*: Example from Spain with the goals to feed water of sufficient quality to the Cortalet lagoon in a Natural Reserve and to stimulate the recovery and establishment of local flora and fauna. The WWTP is of the extended aeration type and consists of a mechanical pre-treatment step and then two parallel treatment lines, each comprising a biological reactor, a clarifier and three effluent polishing ponds. There is also a chemical treatment for phosphorus removal. Further treatment is achieved by means of a wetland system (3 parallel cells) (Davide Bixio, Wintgens, and Bixio 2006).
- *Wetlands USA*: Treated effluent from Arcata WWTP (California, USA), is discharged into 'enhancement wetlands', which are part of the Arcata Marsh and Wildlife Sanctuary. The first treatment steps at the Arcata WWTP consist of bar screens, a grit chamber and two settling tanks for primary treatment. Secondary and partial tertiary treatment is accomplished by two oxidation ponds followed by three parallel FWS (Free water surface) wetlands that were constructed in 1985. After chlorination and de-chlorination, part of the wastewater is released while another part flows into three so-called 'enhancement FWS wetlands'. The 'enhancement wetlands' together with some additional landscape features, are referred to as the Arcata Marsh and Wildlife Sanctuary (Davide Bixio, Wintgens, and Bixio 2006).

For the national regulations of Egypt, Morocco and Tunisia, treatment trains were also identified for all simulated case studies (

Table 6). If limitations also apply to the results, they show that there are available technologies that could treat typical Egyptian, Moroccan, and Tunisian municipal wastewater and secondary effluent of municipal wastewater treatment plants to comply with national regulations. Identified options ranked on cost have a lifecycle treatment cost ranging between 0.16-0.80 USD per cubic meter for reclaimed water. Thus, these options provide reclaimed water at an affordable cost.

Table 6: Top-ranking treatment trains for treating municipal wastewater and secondary effluents to comply with Moroccan, Egyptian, and Tunisian regulations based on cost (C1) and weights (W1)

Ranking	Cost [USD/m³]	Ranking	Cost [USD/m³]
Typical municipal wastewater quality (MWW)			
Moroccan Regulation - Cat A: irrigation of crops to be eaten raw		*Moroccan Regulation - Cat B & C: irrigation of other crops*	
C1-'Wetlands: Nicaragua'	0.16	C1-'Wetlands: Nicaragua'	0.16
W1-'Wetlands: Spain'	0.59	W1-'Wetlands: Spain'	0.59
Egyptian wastewater reuse regulation - Level A: landscape irrigation in urban areas		*Egyptian wastewater reuse regulation - Level B: agriculture purposes in desert areas*	
C1-'Wetlands: USA'	0.80	C1-'Lagooning: Australia I'	0.39
W1-'Only disinfection Benchmark Technology'	1.19	W1-'Wetlands: Spain'	1.01
Tunisian regulation - NT 106.03 standard: irrigation		*Tunisian regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use*	
C1-'Wetlands: Senegal'	0.37	C1-'Only disinfection: Chile'	0.52
W1-'Wetlands: Spain'	0.56	W1-'Wetlands: Spain'	0.56
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw		*Moroccan Irrigation Regulation - Cat B & C: irrigation of other crops*	
C1-No treatment	0.00	C1-No treatment	0.00
W1-No treatment	0.00	W1-No treatment	0.00
Egyptian regulation - Level A: landscape irrigation in urban areas		*Egyptian regulation - Level B: agriculture purposes in desert areas*	
C1-'Direct membrane filtration Benchmark Technology'	0.40	C1-'Direct membrane filtration Benchmark Technology'	0.40
W1-'Wetlands: Spain'	1.01	W1-'Wetlands: Spain'	1.01
Tunisian regulation - NT 106.03 standard: irrigation		*Tunisian regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use*	
C1-'Wetlands: Nicaragua'	0.15	C1-'Wetlands: Nicaragua'	0.15
W1-'Wetlands: Spain'	0.56	W1-'Wetlands: Spain'	0.56

Table 6 show that four treatment trains in addition to the ones defined before (i.e., Wetlands: Spain, Only disinfection Benchmark Technology, and Lagooning: Australia I) have a high potential for the defined case studies:

- *Wetlands, Nicaragua*: Constructed Wetland in Masaya Pilot Plant Nicaragua. The system is treating the domestic wastewater (100 cubic meters per day) generated by 1,000 people living in the city of Masaya, Nicaragua. The scheme comprises pre-treatment (screen and grit tank) and four constructed wetland beds fed in parallel. The area of each wetland bed is about 350 square meters, totaling 1,400 square meters. Effluent from the pilot plant in Masaya can be used for restricted irrigation (Gauss 2008).
- *Wetlands, Senegal*: Example of water reuse for agricultural purpose from Dakar, Senegal. The main wastewater reuse site in urban agriculture in Dakar is Pikine. Of Pikine's total cultivated area of approximately 120 acres (50 ha), about 40 acres (16 ha) makes use of raw wastewater for irrigation. Usually, farmers divert wastewater from the sewage using pipes to load narrow wells located in their plot. From that well, they use water cans to irrigate crops such as lettuce, which grow rapidly. Wastewater treatment using wetlands has been introduced which showed good removals of E.coli and helminth eggs. The treatment lines tested used combinations of four ponds (each 2 m^3) in series: One waste stabilization pond followed by three reed or Vetivera planted stabilization ponds with free water surface and surface water flow (US-EPA 2012).
- *Direct membrane filtration Benchmark Technology*: New concept, which is investigated in several places (Netherland, China, Israel). Micro- or Ultrafiltration of raw wastewater followed by agricultural applications (Van Der Graaf et al. 2005).
- *Only disinfection, Chile*: Treatment train of Copiapó Wastewater Treatment Plant. Water re-use in mining industry and agriculture. The wastewater from Copiapó are directed to Copiapó WWTP, where in the first place the WW is subjected to a primary treatment to retain thick solids, then through a secondary treatment to carry out the oxidation of organic matter by activated sludge. The mixture flows to a separation process of solid and liquid in the clarifier, generating a sludge stream and a treated water stream. The water stream is subjected to chlorination and discharged to Copiapó river (Verzandvoort et al. 2013).

2.2.2. Simulation and lifecycle costs of MADFORWATER project treatment trains

The second objective focuses on assessing the selection of treatment trains from the MADFORWATER projects that have been simulated with the DST. The performance of those trains is not known yet, as pilot plants are being implemented in the MADFORWATER project; however, the lifecycle treatment costs have been calculated for different flow rates in the three target countries (Figure 13). Apart from the train focusing on municipal wastewater, the four other WW treatment trains are specifically designed for industrial wastewater (i.e. olive mill wastewater, textile wastewater, and fruit and vegetable packaging wastewater); and for drainage canal water, which is more specifically addressed to the Egyptian case study. Additionally, to lifecycle treatment costs, the simulation with the DST allows to obtain detailed cost information for the different WW treatment trains that can be considered in the decision-making process.

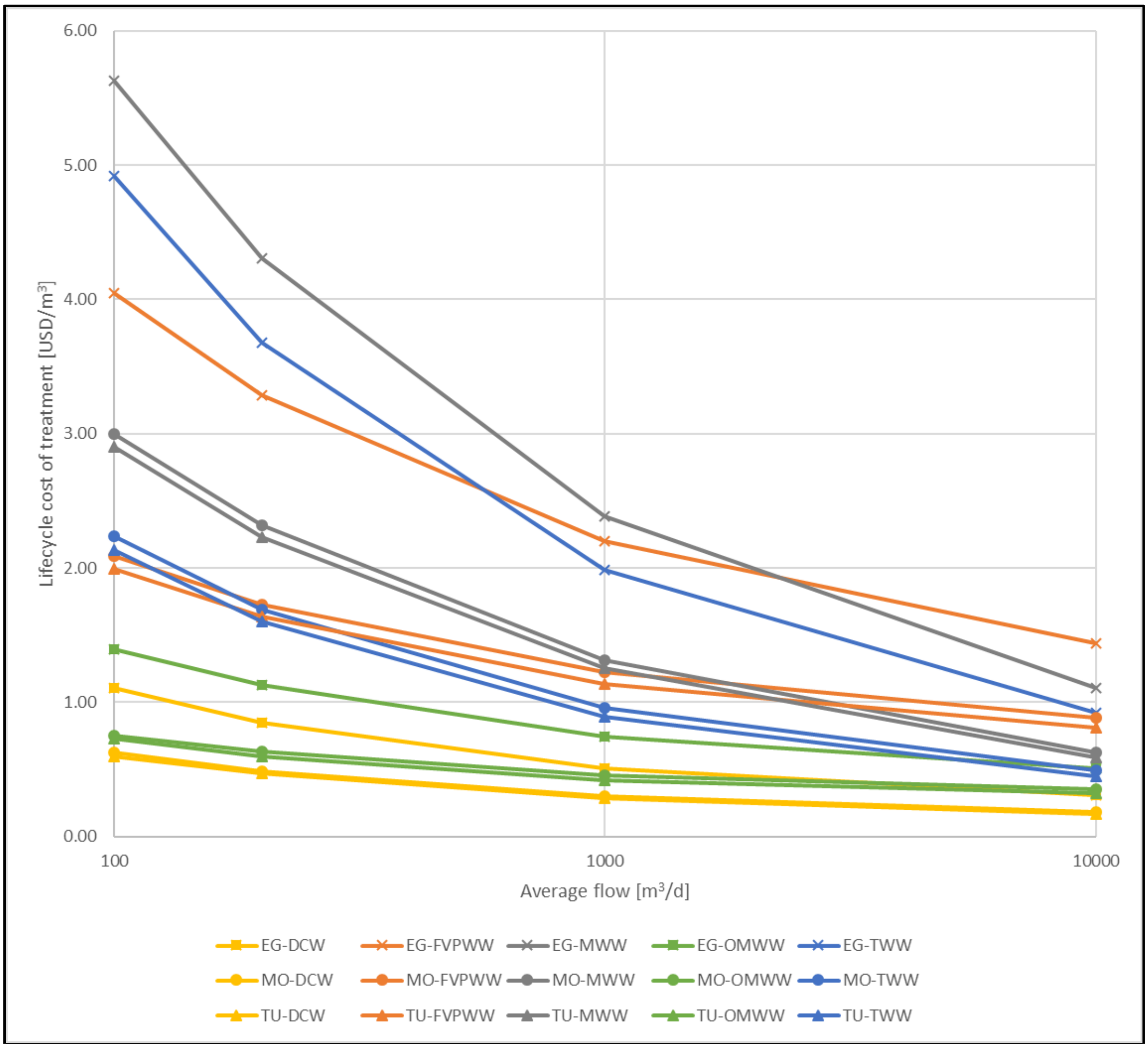


Figure 13: Treatment trains lifecycle costs for different flow rates and countries. EG, MO and TU stand for Egypt, Morocco and Tunisia respectively. DCW stands for Drainage Canal Water, FVPWW stands for Fruit and Vegetable Packaging Wastewater, MWW stands for Municipal Wastewater, OMWW stands for Olive Mill Wastewater, and TWW stnads for Textile Wastewater.

Table 7: Cost factors for selected treatment trains designed for specific types of wastewater in Egypt (EGY), Morocco (MAR), and Tunisia (TUN)

Country	Capital Costs per year [1,000 USD/a]	Capital Expenditure (CAPEX) [1,000 USD]	Land Cost per year [1,000 USD/a]	Energy cost per year [1,000 USD/a]	Labour cost per year [1,000 USD/a]	Other Operation and Maintenance costs per year [1,000 USD/a]	Total costs per year [1,000 USD/a]	End Flow per year [1,000 m³/year]	Cost / m³ [USD /m³]
Treatment train for drainage canal water (DCW) (average flow: 1,000 [m³/d])									
EGY	104	537	38	1	0	42	185	365	0.51
MAR	47	619	15	4	0	42	109	365	0.30
TUN	45	631	14	3	0	42	104	365	0.28
Treatment train for fruit and vegetable packaging wastewater (FVPWW) (average flow: 200 [m³/d])									
EGY	209	1,081	0	1	1	26	237	72	3.28
MAR	90	1,181	0	8	1	26	125	72	1.73
TUN	85	1,195	0	5	3	26	118	72	1.63
Treatment train for municipal wastewater (MWW) (average flow: 10,000 [m³/d])									
EGY	2,811	14,527	290	22	2	821	3,946	3,577	1.10
MAR	1,176	15,355	115	121	1	821	2,234	3,577	0.62
TUN	1,094	15,469	106	77	5	821	2,103	3,577	0.59
Treatment train for olive mill wastewater (OMWW) (average flow: 100 [m³/d])									
EGY	37	194	0	0	0	3	41	30	1.39
MAR	17	219	0	2	0	3	22	30	0.75
TUN	16	223	0	1	1	3	22	30	0.73
Treatment train for textile wastewater (TWW) (average flow: 200 [m³/d])									
EGY	240	1,240	0	1	1	21	263	72	3.68
MAR	95	1,240	0	4	1	21	121	72	1.69
TUN	88	1,240	0	3	3	21	115	72	1.60

2.2.3. Assessment of national-level conditions for water reuse

The simplified and the “expert” (detailed) scored results of the MCA are shown in Table 8 a and b, which bases on an investigation of different indicators (specific results of the indicators Table 57 in supplementary materials).

The simplified assessment shows that the results of Australia are ‘higher’ water reuse level. This indicates the anticipated integration of a country with well-established water reuse practices. The results of Tunisia and Egypt show mostly ‘moderate’ national-levels for water reuse. The results of Egypt and Morocco shows several ‘lower’ national-levels for water reuse. This indicates there is potential for improvement, particularly Morocco and Egypt. As a limitation, the simplified assessment provides a very concise statement on the national-levels for water reuse.

The “expert” (detailed) assessment shows that overall Australia results in ‘moderate’ to ‘higher’ with one ‘lower’ water reuse level. This confirms the anticipated integration of a

country with well-established water reuse practices. Moreover, this anticipated result verifies our multi-criteria analysis. Overall, Tunisia, Egypt, and Morocco did show a high national-levels for water reuse.
Tunisia shows mostly water reuse level of 'higher' to 'moderate' but for 'lower' the thematic subject 'economy'. 'Higher' resulted, because of the key area 'environment' and 'policy & institution'. Regarding 'environment', the results showed a strict guidance regarding the national water reuse regulations in comparison with the international BS ISO 16075-2: 2015 water quality guideline.
Morocco shows mostly a water reuse level of 'higher' to 'moderate' but for the thematic subject 'economy' and 'environment'. 'Higher' resulted, because of the thematic subject 'society' with the indicator 'Share of using improved sanitation services'.
Egypt shows mostly a water reuse level of 'higher' to intermediate values between 'lower' to 'moderate' but 'lower' for the thematic subject 'environment'. 'Higher' resulted, because of the thematic subject 'policy & institution' and 'society'. 'Lower' resulted, because of the thematic subject 'water management' and 'environment'.
The results of the thematic subject's 'society' and 'policy & institution' demonstrate 'higher' to 'moderate' level of water reuse. The 'moderate' did result for 2 out of 10 possible results. This indicates there are favourable condition for water reuse in these thematic subjects. The results of the thematic subject's 'economy', 'water management' and 'environmental' resulted with the most 'lower' water reuse level. This indicates the main barriers are in these thematic subjects.

Table 8: The results of the national-level conditions for water reuse assessment. 'Lower' national-level conditions for water reuse is in red and equivalent to the score '1', moderate national-level conditions for water reuse in yellow and equivalent to the score '2', 'higher' national-level conditions for water reuse in green and equivalent to the score '3'. The aggregated values can in addition include 'intermediate values between '1' and '2' in orange shades, and '2' and '3' in light green shades. Ts stands for Thematic subject. Ec stands for economy. WM stands for water management. P & I stand for policy and institution. L stands for legislation. S stands for society. En stands for environment. '-'stand for 'no data available' or 'not defined. a: The simplified results; b: the "expert" (detailed) results

a:

Ts	Key question	Indicators	Morocco		Egypt		Tunisia		Australia	
			aggregated	detailed	aggregated	detailed	aggregated	detailed	aggregated	detailed
Ec	-What is the **water pricing for agriculture**?	Water pricing for agriculture	1	1	1	1	1.5	1	3	3
	-What are the **financial subsidies** for water use in agriculture?	Financial subsidies		1		1		2		-
WM	- What is the **share of treated to produced volume** of industrial and municipal wastewater?	Share of annual treated to produced industrial and municipal wastewater	1	1	2	2	2	2	3	3
P&I	-What is the degree of **implementation of national monitoring and reporting** system?	Degree of implementation of national monitoring and reporting system		-	2	2	3	3	-	-
L	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	Compliance for food and non-food crop irrigation with reclaimed water	3	3	2	2	2	2	-	-
S	-What is the **social acceptance** of a country towards water reuse for agriculture?	Social acceptance in a country towards the water reclamation for agriculture	-	-	-	-	-	-	-	-
En	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	Compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guideline	1	1	1	1	3	3	3	-

b:

Ts	Key question	Indicators	Morocco		Egypt		Tunisia		Australia	
			aggregated	detailed	aggregated	detailed	aggregated	detailed	aggregated	detailed
Ec	-What is the **official financial development assistance** (gross expenditure) for water supply and sanitation?	Total official financial development (gross disbursement) assistance for water supply and sanitation for water supply and sanitation by recipient per WW production in a country and year	1.3	1	1.33	1	2	2	3	-
	-What is the level of **economic water security**?	Economic water security		2		2		3		3
	-What is the **water pricing for agriculture**?	Water pricing for agriculture		1		1		1		3
	-What are the **financial subsidies** for water use in agriculture?	Financial subsidies		-		1		2		-
WM	-What is the **transboundary water dependency ratio**?	Transboundary Water Bodies Dependency Ratio in the Northern African region	2	3	1.5	1	1.7	1	2.5	-

Ts	Key question	Indicators	Morocco		Egypt		Tunisia		Australia	
			aggregated	detailed	aggregated	detailed	aggregated	detailed	aggregated	detailed
	-What is the share of **produced volume** of industrial and municipal wastewater per total population in a country?	Share of annual produced industrial and municipal wastewater volume per total population in a country		3		1		2		1
	- What is the **share of treated to produced volume** of industrial and municipal wastewater?	Share of annual treated to produced industrial and municipal wastewater		1		2		2		3
	-What is the share of **harvested irrigated crop area per cultivated area**?	Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)		1		2		2		3
P&I	-What is the **proportion of monitoring and reporting** system **in comparison to other countries**?	Proportion of monitoring and reporting system between African countries reported on by country	-	-	2.5	2	3	3	-	-
	-What is the degree of **implementation of national monitoring and reporting** system?	Degree of implementation of national monitoring and reporting system		-		3		3		-
L	- What is the **quality of contract enforcement, property rights, and the courts** in each country?	World governance index, rule of law	2.5	2	1.5	1	2	2	3	3
	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	Compliance for food and non-food crop irrigation with reclaimed water		3		2		2		-
S	-What is the degree of **implementation of equitable water and wastewater tariffs**	Degree of implementation of equitable and efficient water supply and wastewater tariffs		-		3		2		-
	-What share of population is using **improved sanitation services**?	Share of using improved sanitation services	3	3	3	3	2.5	3	3	3
	-What is the **social acceptance** of a country towards water reuse for agriculture?	Social acceptance in a country towards the water reclamation for agriculture		-		-		-		-
En	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	Compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guideline	2	1	1	1	3	3	3	-
	- What is the share of the **area equipped for irrigation that has become salinized**?	Percent of area equipped for irrigation that has become salinized		3		-		3		3

2.3. Establishment of exemplary basin-scale and national wastewater management strategies including economic instruments

Based on the case studies presented in sections 2.2.1 and 2.2.2, we established exemplary basin-scale and national wastewater management strategies including economic instruments for Egypt, Morocco and Tunisia. We built the exemplary strategies upon the top-ranking options from the DST and from the MADFORWATER project pilot schemes. These options and corresponding technologies are complemented by the results of the multi-criteria decision analysis that identifies barriers, drivers and additional measures recommended to foster the implementation of sound solutions for water reuse in the region.

This section covers the application and resulting technologies of the DST for the three countries and the results of the four pilot plants. Table 9 gives a brief overview of the application of the DST and the resulting two technologies with the lowest cost of treatment for each country and the wastewater type treatment for the pilot plants. More detailed results are presented in the relevant sections below. In the following sections, a country-specific analysis was carried out with the DST.

Table 9: Overview of resulting top-ranking options from the DST application and the MADFORWATER pilots in Egypt, Morocco and Tunisia

Egypt	***Morocco***	***Tunisia***
DST-based results	*DST-based results*	*DST-based results*
EG1: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops **Technology suggested:** No treatment necessary	**MO1**: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops **Technology suggested:** No treatment necessary	**TU1**: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops **Technology suggested:** No treatment necessary
EG2: Reuse of typical municipal wastewater for agriculture purposes in desert areas **Technology suggested:** Lagooning: Australia I	**MO2**: Reuse of typical municipal wastewater for irrigation of crops to be eaten raw. **Technology suggested:** Wetlands: Nicaragua	**TU2**: Reuse of municipal WWTP typical secondary effluent for irrigation (NT 106.03 standard) **Technology suggested:** Wetlands: Nicaragua
	MO3: Specific case of M'Zar Wastewater treatment plant with multiple reusers**.**	
Pilot-based result	*Pilot-based result*	*Pilot-based result*
EG3: Reuse of drainage Canal Water for irrigation **Technology suggested:** MADFORWATER Pilot (Lake Manzala, Egypt)	**MO4:** Reuse of municipal WWTP tertiary effluent for olive trees irrigation **Technology suggested:** MADFORWATER Pilot (Agadir, Morocco)	**TU3:** Reuse of municipal WWTP secondary effluent for irrigation **Technology suggested:** MADFORWATER Pilot (Chotrana, Tunisia) **TU4:** Reuse of textile WW for non-food crops irrigation

		Technology suggested: MADFORWATER Pilot (Gwash, Tunisia)

2.3.1. Egypt

Egypt has been suffering from severe water scarcity in recent years. Egypt has only 20 cubic meters per person per year of internal renewable freshwater resources, and as a result the country relies heavily on the Nile River for its main source of water. With a rising population and a fixed supply, the country has less water per person each year. The River Nile is the backbone of Egypt's industrial and agricultural sector and is the primary source of drinking water for the population. Egypt is already below the United Nations' water poverty threshold, and by 2025 the UN predicts it will be approaching a state of "absolute water crisis" (Eco Mena 2017; The Guardian 2015).

2.3.1.1. Mapping of waste water reuse potential for irrigation in Egypt

The mapping of water reuse potential is reproduced from the deliverable 1.2 in the H2020 MADFORWATER project (Snethlage et al. 2018). The methodology applied aimed at identifying hotspots, with higher potential for water reuse (Figure 14).

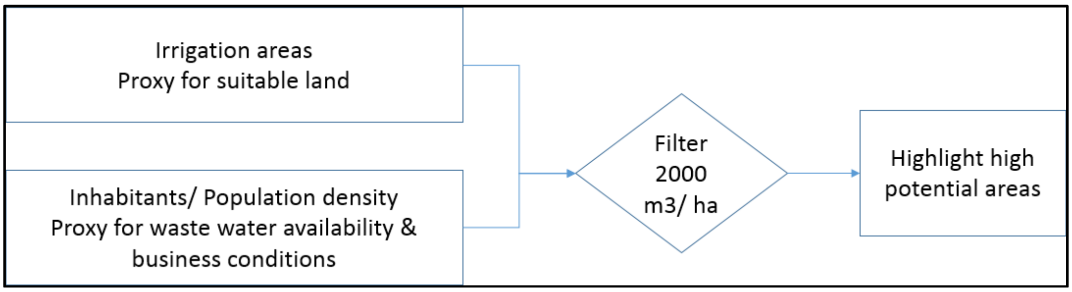
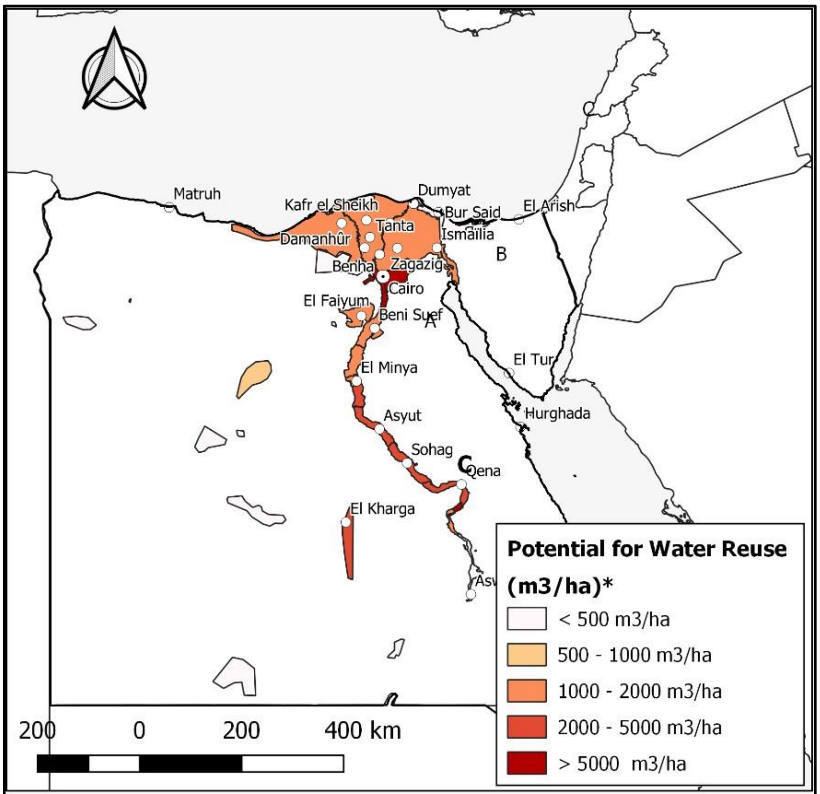


Figure 14: Simplified approach to enable wastewater reuse potential mapping in Morocco, Tunisia, and Egypt

Egypt with its concentration of large population along the Nile valley and the abundance of a number of oasis offers in principle very favorable conditions for the wastewater reuse (see Figure 15). Clear focus areas could be instead all cities such as Qena (230,000 inh.), Asyut (400,000 inh.). El Fayoum (440,000 inh.), or the outskirts of Cairo with areas such as Benha (196,000 inh.). Being concentrated in the Nile valley, traditionally the distance to irrigated areas is short. Institutionally, the best opportunities for wastewater reuse would be at local level to solve water quality and health problems at local scale with local initiatives. Currently, Egyptian laws prohibit such local wastewater reuse options. However, by law the drainage systems must comply with a certain water quality standard (as listed under the Law 48), which can often not be met. Efforts to support the reuse of wastewater should therefore mainly concentrate on increasing the wastewater treatment capacity (in quantity, quality, and areal coverage). The meanwhile reached aggravation of the current situation can be stressed by the fact that the government had to terminate already the operation of drinking water supply installations, taking water from irrigation canals where drainage water was reused upstream. Ongoing efforts as e.g. to reuse the water from the Bahr Baqr drain; underline the current momentum in Egypt to advance the wastewater reuse in this way.



*Calculations performed at irrigation unit level by dividing the total urban wastewater production by the irrigated area available

Figure 15: Egypt current wastewater production divided by irrigation area at district level.

Emerging urbanized areas in the new lands with the availability of flat desert areas are in their closer vicinity, offer the potential to construct the collection and monitoring system specifically and from the beginning accordingly to the needs of an effective and safe wastewater reuse (see Figure 16). Advanced and adapted treatment systems can be installed to facilitate the purification process on demand for a future reuse as well. Further options that would be of interest could be the increased reuse from agrofood industry wastewater with its defined and nutrient rich composition. The agricultural re-use must not necessarily lie in the production of food crops only, but could consider the production of aromatic plants, seeds, by- products for the bio-economy or e.g. proteins for the fodder industries.

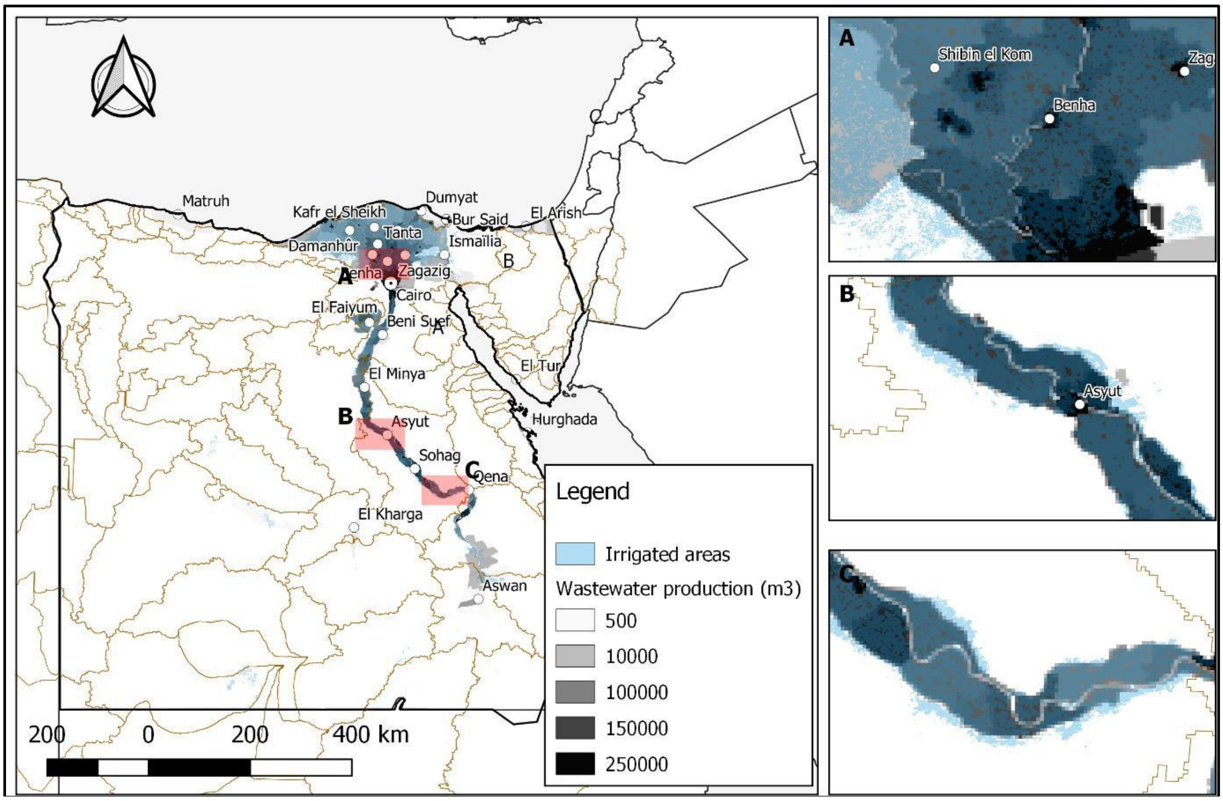


Figure 16: Egypt current location of wastewater production hotspots and location of irrigated areas

2.3.1.2. Water reuse options based on the DST-Assessment

The assessment presented in section 2.2.1, resulted in several options that could treat municipal wastewater (either typical raw wastewater or typical secondary effluent of existing WWTP) to the desired quality in order to comply with the corresponding regulation (either national or ISO). In order to select top-ranking options out of all the feasible ones, we proceeded to a ranking based on the lowest cost of treatment and resulted in four top-ranking scenarios for water reuse in Egypt (

Table 10). From this ranking, we further selected two scenarios as building blocks for basin scale strategies presented further in this section. The two selected scenarios are highlighted in grey in

Table 10. These are:

- **EG1**: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops
  Technology suggested:
  No treatment necessary
- **EG2**: Reuse of typical municipal wastewater for agriculture purposes in desert areas
  Technology suggested:
  Lagooning: Australia I

Table 10: Four top-ranked options for water reuse in Egypt based on lowest cost of treatment (treatment of 10,000 [m3/d])

Ranking	Wastewater	End-use – water quality regulation	Technology	Cost of treatment [USD/m^3]
1	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	No treatment	0
2	MAC - MWW - Typical Municipal Wastewater quality	Egyptian wastewater reuse regulation - Level B: agriculture purposes in desert areas	Lagooning: Australia I	0.39
3	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Lagooning: Australia I	0.39
4	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	Lagooning: Australia I	0.39

2.3.1.3. Water reuse option based on the MADFORWATER project pilot for drainage canal wastewater (DCWW)

- **EG3:** Reuse of drainage Canal Water for irrigation. **Technology suggested:** MADFORWATER Pilot (Lake Manzala, Egypt)

In Egypt, agricultural drainage water is considered as a valuable water source that is collected and re-used for irrigation through a well-developed irrigation and drainage canal system. However, primary-treated and untreated municipal wastewater (MWW) is discharged into the drainage canals, which in turn convey organic contaminants, nitrogen and pathogens to the main drains. No treatment is actually performed on drainage canal water before it is used for irrigation of agricultural land. The MADFORWATER pilot plant for drainage canal water treatment has been installed in December 2018 in an experimental station operated by the National Water Research Center (NWRC) of Egypt near Lake Manzala, Egypt. The pilot plant with a capacity of 250 m^3/day consists of the following components: (i) a 500 m^3 lagooning / sedimentation pond and (ii) three different types of Hybrid Constructed Wetlands (HCW). The first result indicate that the Cascade Hybrid Constructed Wetland is the most effective one. The pilot plant with its capacity would be able to annually treat about 91,250 m^3 drainage canal wastewater. According to the new decision support tool, the costs of this technology amount to 1.08 EGP/m^3 or 0.42 USD/m^3. Considering the produced MWW in Egypt (FAO, 2016)[2] of around 7,080 Mio m^3/year and the cost of the technology, the pilot plant would be able to treat 1.3% of the annual DCWW at a cost of 98,550 EGP or 38,325 USD. The results concerning the social aspects of the national-level conditions for water reuse assessment showed a positive result for Egypt. This means that, according to the 2nd Arab State of Water Report (2012), 94.7% of the Egyptian population already uses improved sanitation services. Concerning the environmental aspects of the water reuse assessment, the results

[2] AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). Website accessed on [13/03/2018 14:58]

revealed a low compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guide.

2.3.1.4. Barriers and measures to foster implementation

In Table 11 the detailed scored result, strategy excerpt, identified barriers and measures / (economic) instruments are shown. The scored results very between 1 (lower) to 3 (higher) for which different barriers were identified. These can be overcome by economic and non-economic instruments. The economic instruments include often price based measures. The non-economic include increase enforcement and capacity building in general and increase of number of treatment technology and MADFORWATER technologies.

Table 11: Egypt's result of multi criteria analysis of different key questions, strategy excerpt, identified barriers and (economic) instruments. The results of the national-level conditions for water reuse assessment. 'Lower' national-level conditions for water

Ts	Key question	Score detailed	Strategy excerpt	Identified barrier	Measures / instruments (economic)
Ec	-What is the **official financial development assistance** (gross expenditure) for water supply and sanitation?	1	Financial support is lower	Limited growth based on financial support per WW produced	P2: Subsidies or other financial assistance (e.g. assisted loans)
	-What is the level of **economic water security**?	2	Moderate water security	Improve water security	N1: Insurance Q1: Quotas (command-and-control) Q2: Water markets/ water trading
	-What is the **water pricing for agriculture**?	1	Higher for water pricing costs	Water is available too cheap to cover the costs	P1: Pricing/ water tariffs P3: Taxes
	-What are the **financial subsidies** for water use in agriculture?	1	High financial subsidies	Water is available for free, consequently no incentive to save water	P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes
WM	-What is the **transboundary water dependency ratio**?	1	Higher transboundary water dependency	High water supply dependency on neighbouring countries	P1: Pricing/ water tariffs P3: Taxes
	-What is the share of **produced volume** of industrial and municipal wastewater per total population in a country?	1	Higher volume of wastewater produced per total population	High volume of wastewater to be treated per population	Q1: Quotas (command-and-control) Q2: Water markets/ water trading Non-economic instrument: Capacity building and technology scale up
	- What is the **share of treated to produced volume** of industrial and municipal wastewater?	2	Moderate level of treated to produce wastewater volume	Moderate share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology Non-economic instrument: Increase of number of treatment technology
	-What is the share of **harvested irrigated crop area per cultivated area**?	2	Moderate share of harvested irrigated crop area per cultivated area	Moderate level of control irrigation per cultivated area.	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology Non-economic instrument: Increase of MADFORWATER technology

Ts	Key question	Score detailed	Strategy excerpt	Identified barrier	Measures / instruments (economic)
P&I	-What is the **proportion of monitoring and reporting** system **in comparison to other countries**?	2	Moderate proportion of monitoring in international context	Moderate proportion of monitoring in international context	Non-economic instrument: increase enforcement in general
	-What is the degree of **implementation of national monitoring and reporting** system?	3	Compliance with national monitoring and reporting system	No	No
L	- What is the **quality of contract enforcement, property rights, and the courts** in each country?	1	In international comparison: Lower level of quality of contract enforcement, property rights, and the courts	Lower level of quality of contract enforcement, property rights, and the courts	Non-economic instrument: Increase enforcement in general
	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	2	Partly compliance with legislation	Not allowed to irrigate non-food crop	Non-economic instrument: Adapt legislation
S	-What is the degree of **implementation of equitable water and wastewater tariffs**	3	Higher degree of implementation of equitable water and wastewater tariffs	No	
	-What share of population is using **improved sanitation services**?	3	Wide use of sanitation services	No, yet there is a large amount of treated WW that could be used for water reclamation	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning for new technologies P3: Taxes for fresh water Non-economic instrument: Increase of number of treatment technology incl. MADFORWATER technolgoies
	-What is the **social acceptance** of a country towards water reuse for agriculture?	-	N/Av	N/Av	N/Av
En	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	1	Lower compliance	Stricter implementation of regulation and higher compliance with ISO 16075-2	Non-economic instrument: Increase enforcement in general
	- What is the share of the **area equipped for irrigation that has become salinized**?	-	N/Av	N/Av	N/Av

2.3.2. Morocco

Although Morocco is still far from the “extremely high” ratio of water withdrawal to supply, as the case in many Middle Eastern countries, the kingdom is still among the 45 countries facing water scarcity. It is confronted with dwindling groundwater reserves and a strong dependence on rain-fed agriculture. Cultivable land is compromised because of water shortages and soil erosion. These factors are seriously aggravating rural poverty, and the gap between the richest and poorest population segments has widened (Morocco World News 2017; Espace Associatif 2012; USAID 2017).

2.3.2.1. Mapping of wastewater reuse potential for irrigation in Morocco

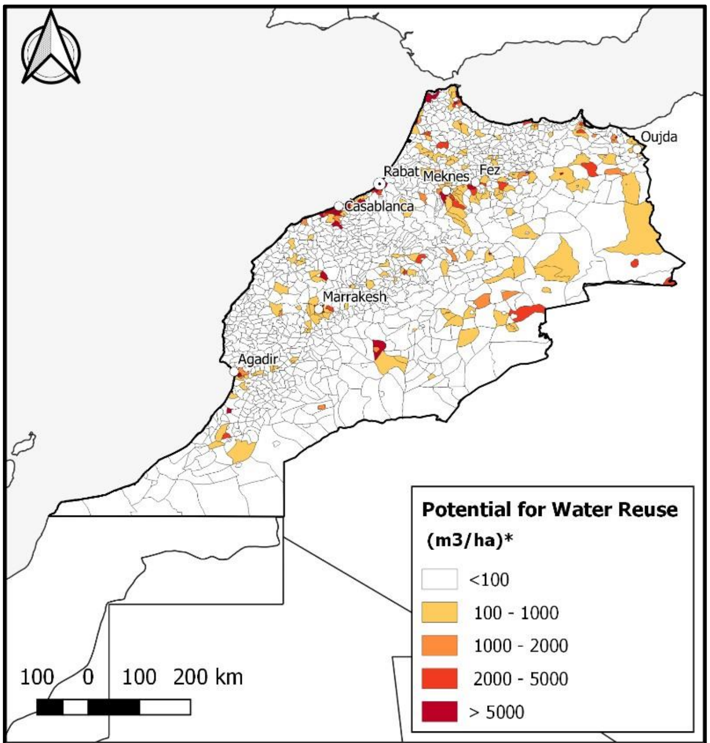
The mapping of water reuse potential is reproduced from the deliverable 1.2 in the H2020 MADFORWATER project (Snethlage et al. 2018).

The use of raw waste water for irrigation is widely applied in Morocco, as Choukr-Allah (2005) reported (Table 12). However, the level of treated waste water reuse is still low in the country. But the rapid increase of wastewater produced and collected in urban areas experienced during the last decades evidences the great potential. According to the National Water Resources Plan (PNA), it is expected that by 2030 the generated wastewater will grow to 900 million m3. The PNA establishes an annual target of 325 million m^3 of wastewater to be reused by 2030, mainly for irrigation (142 million m^3) and landscaping/golf courses (133 million m^3). Other uses such as reuse for industry and groundwater recharge are also considered in the plan.

Table 12: Selected areas of raw wastewater reuse in agriculture (from Choukr-Allah 2005 with reference to CSEC data from 1994)

Area	Surface (ha)	Crops
Marrakesh	2000	Cereals, fruit trees
Meknes	1400	Cereals, fruit trees
Ouijda	1175	Cereals, fruit trees
Fès	800	Fruit trees
El Jadida	800	Foddder

As it could be stated in the following maps, using the wastewater from Agadir or Marrakesh would be most likely restricted to utilize the water from rather the outer skirts of cities, leading to a shorter transportation distance (see Figure 17). Within such more urbanized parts, specific production of high value crops and by products (herbs & special crops for aromatic oils) in very intensive production systems would be a firs



*Calculations performed at distric level by dividing the total urban wastewater production by the irrigated area available

Figure 17: Morocco current Wastewater production divided by irrigated area at district level

Especially the smaller towns in the region east of Agadir with the areas around Taroudant or Oulad Berhil offer a very interesting opportunity (see Figure 18). The high business potential is furthermore characterized by a nearby located clustering of agri-enterprises south of Agadir and along the N1 in the surrounding of Tin Mansour (2 hrs drive to Oulad Berhil). The reasonable travel distances would allow investors to engage in new upcoming endeavors in the East of Agadir. The very similar pattern can be obtained in the surrounding east of Marrakesh, with potential priority areas around Fquih Ben Salah (102,000 inhabitants in 2014). This region is offering a promising combination of water availability, short distances to production areas, and the commercial center of Marrakesh. Even if the total amount of waste water is less than in Agadir or Marrakesh region, the city of Meknes and its surroundings could be a very interesting priority area too. This confirms and underlines the advantage of looking to urban cells or resorts that are large enough to produce wastewater and close enough to realize an efficient use.

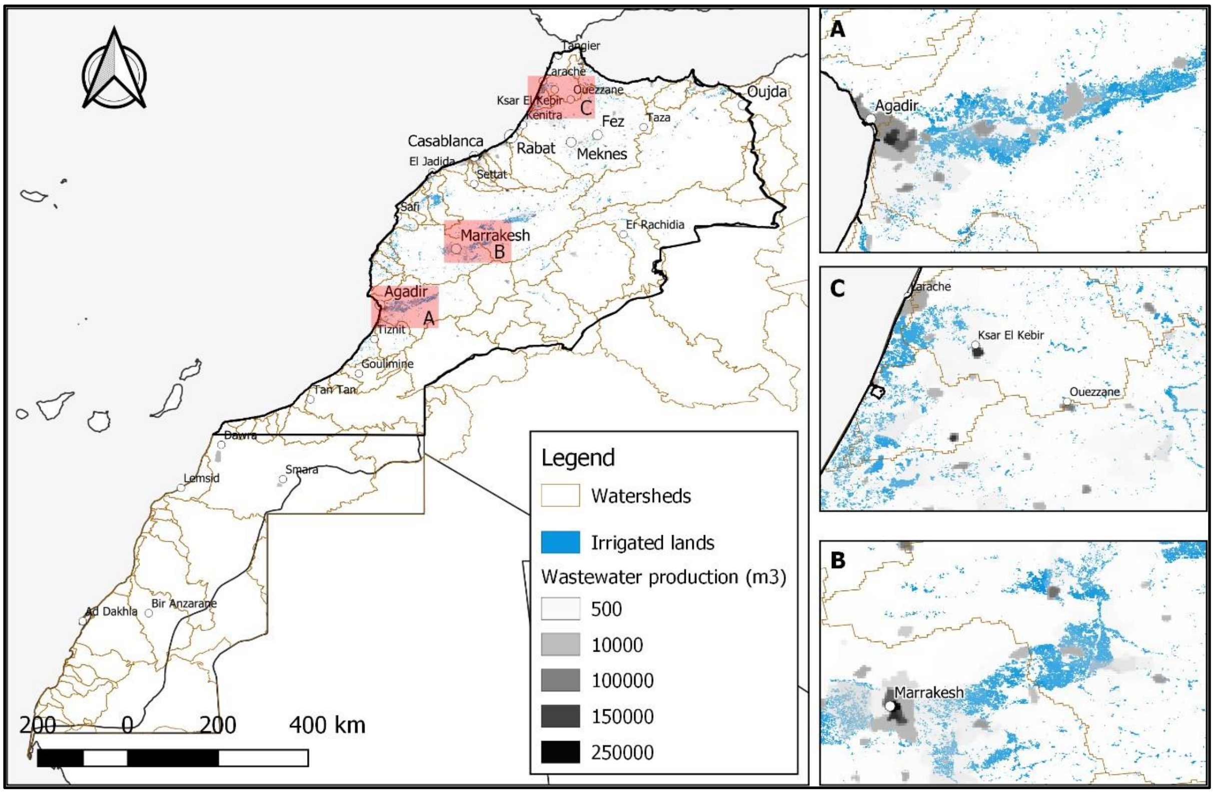


Figure 18: Morocco current location of wastewater production hotspots and location of irrigated areas

2.3.2.2. Water reuse options based on the DST-Assessment

The assessment presented in section 2.2.1, resulted in several options that could treat municipal wastewater (either typical raw wastewater or typical secondary effluent of existing WWTP) to the desired quality in order to comply with the corresponding regulation (either national or ISO). In order to select top-ranking options out of all the feasible ones, we proceeded to a ranking based on the lowest cost of treatment and resulted in four top-ranking scenarios for water reuse in Morocco (Table 13).

From this ranking, we further selected two scenarios as building block for basin scale strategies presented further in this section. The two selected scenarios are highlighted in grey in Table 13. These are:

- **MO1**: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops
  Technology suggested:
  No treatment necessary
- **MO2**: Reuse of typical municipal wastewater for irrigation of crops to be eaten raw.
  Technology suggested:
  Wetlands: Nicaragua

We didn't highlight the options ranked second and third, as it is already reflected by the scenario **MO1**. According to our analysis, the reuse of municipal WWTP typical secondary effluent based on the data assumed comply with different regulations and guidelines:

- ISO Cat. C: Agricultural irrigation of non-food crops
- Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw
- Moroccan Irrigation Regulation - Cat B & C: irrigation of other crops

If the secondary effluent could be compliant with Moroccan regulations, we recommend to consider a disinfection step before reusing it for crops to be eaten raw, as this is a recurrent requirement in European and international guidelines for water reuse. As we cannot guarantee that a disinfection step is considered for the second ranking option, we rather consider the option ranking fourth for further consideration.

Table 13: Four top-ranking scenarios for water reuse in Morocco based on lowest cost of treatment (treatment of 10,000 [m3/d])

Ranking	Wastewater	End-use – water quality regulation	Technology	Cost of treatment [USD/m^3]
1	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	No treatment	0
2	MAC - MWW - Typical Effluent Municipal Wastewater quality	Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw	No treatment	0
3	MAC - MWW - Typical Effluent Municipal Wastewater quality	Moroccan Irrigation Regulation - Cat B & C: irrigation of other crops	No treatment	0
4	MAC - MWW - Typical Municipal Wastewater quality	Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw	Wetlands: Nicaragua	0.16

2.3.2.3. Water reuse options based on the DST-Assessment and specific data provided by local project partners

- **MO3**: Specific case of M'Zar Wastewater treatment plant with multiple reusers.

An additional water reuse option has been analyzed based on data for a specific case that was collected by means of a questionnaire. This case concerns the tertiary effluent of the M'Zar wastewater treatment plant (WWTP) in Agadir (Morocco), which could potentially supply multiple end-reuser. The collected data were therefore entered into the DST to perform an assessment. The tertiary effluent of the WWTP has an average flow of 75,000 [m^3/d] and its corresponding quality is presented in in Table 15. Three different (re) users were identified, as presented in Figure 19 and Table 14.

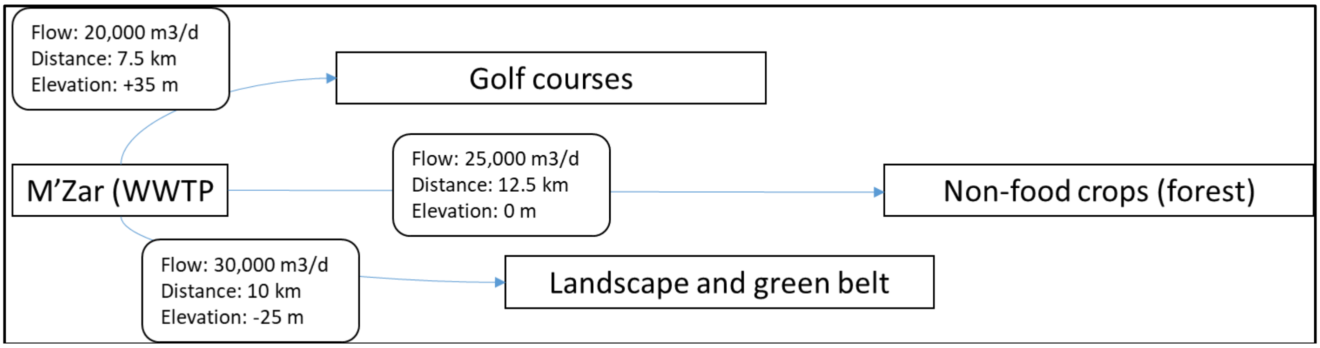


Figure 19: Three potential reusers of the M'Zar WWTP tertiary effluent

Table 14: Input data of the specific case study

Intended (re)user	Quantity required by the (re)user (m3/d)	Distance from the WWTP	Elevation difference (+uphill, – downhill)	How much would the intended (re)user pay?	Select the required water quality for this intended use.
Golf Courses	20 000	From 5 to 10 km	+ 35 m	2.5 MAD/m3	ISO- Cat. C: Agricultural irrigation of non-food cropsISO- Cat. C: Agricultural irrigation of non-food crops
Landscape and green belt	30 000	From 5 to 15 km	- 25 m	2.5 MAD/m3	ISO- Cat. C: Agricultural irrigation of non-food cropsISO- Cat. C: Agricultural irrigation of non-food crops
Nonfood crops (Forest)	25 000	From 5 to 30 Km		2.0 MAD/m3	ISO- Cat. C: Agricultural irrigation of non-food cropsISO- Cat. C: Agricultural irrigation of non-food crops

Table 15: Inflow water quality parameter

	Turb	TSS	BOD	COD	TN	TP	FC	TC
Quality	*NTU*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*mg/L*	*No/100ml*	*No/100ml*
	0.46	**12**	**17**	**46**	**1**	**6**	**2**	**18**

TDS	Nitrate	Bicarbonate	EC
mg/L	mg N/L	mg/L	dS/m
720	**260**	**520**	**3.6**

In order to perform the assessment, we had to select a water quality regulation to comply with for the intended reuse. We considered the ISO Guidelines - Cat. C: Agricultural irrigation of non-food crops as most appropriate for the intended reuses. The results obtained showed that the tertiary effluent quality indicated already complies with this regulation and that no treatment step would be required for any of the three end-users.

However, one should note that the ISO guideline do not specify any limit value for nitrates and this parameter was not considered. It also appears that the nitrate value of the tertiary effluent is higher than the Moroccan regulation categories A, B and C (i.e., 30 mg/l). In case this water reuse option is further developed, a deeper assessment of nitrate should be considered and an eventual nitrification/denitrification step could be considered before reuse. The DST applied has limitations for the specific case of nitrate and could not be applied for this parameter. Further analysis was considered without treatment required to comply with ISO guidelines.

Even though the result does not require any treatment, one should consider that the distribution costs are very significant. Particularly in the case of an uphill elevation, the distribution cost would be around 2.20 USD/m^3 with a quantity of 20,000 m^3 required by the end-user. However, the distribution cost for a downhill pipeline would, according to the DST analysis, amount to 0.06 USD/m^3 with a quantity of 30,000 m^3 required by the end-user, as shown by the distribution costs analysis performed with the DST (Table 16). The only profitable option (revenue from the end-user higher than the distribution cost) is for landscape and green belt supply with reclaimed water. For the other two options, good alternatives to provide cost-efficient distribution should be further investigated.

Table 16: Agadir case study treatment option and cost results

End-user	**Treatment option**	**Cost of treatment** [USD/m^3]	**Distribution cost** [USD/m^3]	**Cost-Revenue** [USD/m^3]
Golf Courses	No treatment	0	2.21	1.88 (loss)
Landscape and green belt	No treatment	0	0.06	-0.16 (profit)
Nonfood crops (Forest)	No treatment	0	1.19	1.50 (loss)

2.3.2.4. Water reuse options based on the MADFORWATER project pilots

- **MO4:** Reuse of municipal WWTP tertiary effluent for olive trees irrigation. **Technology suggested:** MADFORWATER Pilot (Agadir, Morocco)

The second pilot plant where the MWW treatment process has been applied is located in Agadir, Morocco in the Souss-Massa region. The pilot plant for municipal wastewater treatment and agricultural reuse relies on an existing wastewater treatment plant within the station M'zar in Agadir, with a capacity of 75 000 m^3/day. This extrapolates to an annual treatment volume of 27.375 Mio m^3. The plant is articulated on the following treatment sections: (i) a 150 000 m^3 anaerobic lagoon, (ii) 64 sand filtration unit, and (iii) an UV-based disinfection unit. This treatment scheme allows the production of a high-quality effluent. Considering the total annual volume of 28 Mio m^3 MWW that was collected in the Souss-Massa Basin in 2011 (Redouane et al., 2017) and the treatment costs of 1.79 MAD/m^3 or 1.04 USD/m^3, the pilot plant is capable to treat 97.8% of the MWW generated in this region at a cost of 49 Mio MAD or 28.5 Mio USD. From a social point of view, 76.7% of Moroccans have improved sanitation services, representing a positive result. In terms of environmental considerations, the results revealed a low compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guide.

2.3.2.5. Barriers and measures to foster implementation

In Table 17 the detailed scored result, strategy excerpt, identified barriers and measures / (economic) instruments are shown. The scored results very between 1 (lower) to 3 (higher) for which different barriers were identified. These can be overcome by economic and non-economic instruments. The economic instruments include often price based measures. The non-economic include increase enforcement and capacity building in general and increase of number of treatment technology and MADFORWATER technologies.

Table 17: Morocco's result of multi criteria analysis of different key questions, strategy excerpt, identified barriers and (economic) instruments. The results of the national-level conditions for water reuse assessment. 'Lower' national-level conditions for water reuse is in red and equivalent to the score '1', moderate national-level conditions for water reuse in yellow and equivalent to the score '2', 'higher' national-level conditions for water reuse in green and equivalent to the score '3'. Ts stands for Thematic subject. Ec stands for economy. WM stands for water management. P & I stand for policy and institution. L stands for legislation. S stands for society. En stands for environment. '-'stand for 'no data available' or 'not defined

Ts	Key question	Score detailed	Strategy excerpt	Identified barrier	Measures / instruments (economic)
Ec	-What is the **official financial development assistance** (gross expenditure) for water supply and sanitation?	1	Financial support is lower	Limited growth based on financial support per WW produced	P2: Subsidies or other financial assistance (e.g. assisted loans)
	-What is the level of **economic water security**?	2	Moderate water security	Improve water security	N1: Insurance Q1: Quotas (command-and-control) Q2: Water markets/ water trading
	-What is the **water pricing for agriculture**?	1	Higher for water pricing costs	Costs of water pricing is too low to cover the actual costs	P1: Pricing/ water tariffs P3: Taxes
	-What are the **financial subsidies** for water use in agriculture?	-	N/Av	N/Av	N/Av
WM	-What is the **transboundary water dependency ratio**?	3	Lower transboundary water dependency	No	No
	-What is the share of **produced volume** of industrial and municipal wastewater per total population in a country?	3	Lower volume of wastewater produced per total population	No	No
	- What is the **share of treated to produced volume** of industrial and municipal wastewater?	1	High WW treatment potential available	Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology Non-economic instrument: Increase of number of treatment technology
	-What is the share of **harvested irrigated crop area per cultivated area**?	1	Lower share of harvested irrigated crop area per cultivated area	Lower share of harvested irrigated crop area per cultivated area	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at

Ts	Key question	Score detailed	Strategy excerpt	Identified barrier	Measures / instruments (economic)
					the beginning of new technology Non-economic instrument: Increase of MADFORWATER technology
P&I	-What is the **proportion of monitoring and reporting** system **in comparison to other countries**?	-	N/Av	N/Av	N/Av
	-What is the degree of **implementation of national monitoring and reporting** system?	-	N/Av	N/Av	N/Av
L	- What is the **quality of contract enforcement, property rights, and the courts** in each country?	2	In international comparison: Moderate level of quality of contract enforcement, property rights, and the courts	Moderate level of quality of contract enforcement, property rights, and the courts	Non-economic instrument: Increase enforcement in general
	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	3	Compliance with legislation	No	No
S	-What is the degree of **implementation of equitable water and wastewater tariffs**	-	N/Av	N/Av	N/Av
	-What share of population is using **improved sanitation services**?	3	Wide use of sanitation services	No, yet there is a large amount of treated WW that could be used for water reclamation	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning for new technologies P3: Taxes for fresh water Non-economic instrument: Increase of number of treatment technology incl. MADFORWATER technolgoies
	-What is the **social acceptance** of a country towards water reuse for agriculture?	-	N/Av	N/Av	N/Av
En	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	1	Lower compliance	Stricter implementation of regulation and higher compliance with ISO 16075-2	Non-economic instrument: Increase enforcement in general
	- What is the share of the **area equipped for irrigation that has become salinized**?	3	Higher share of the area equipped for irrigation that has become salinized	No	No

2.3.3. Tunisia

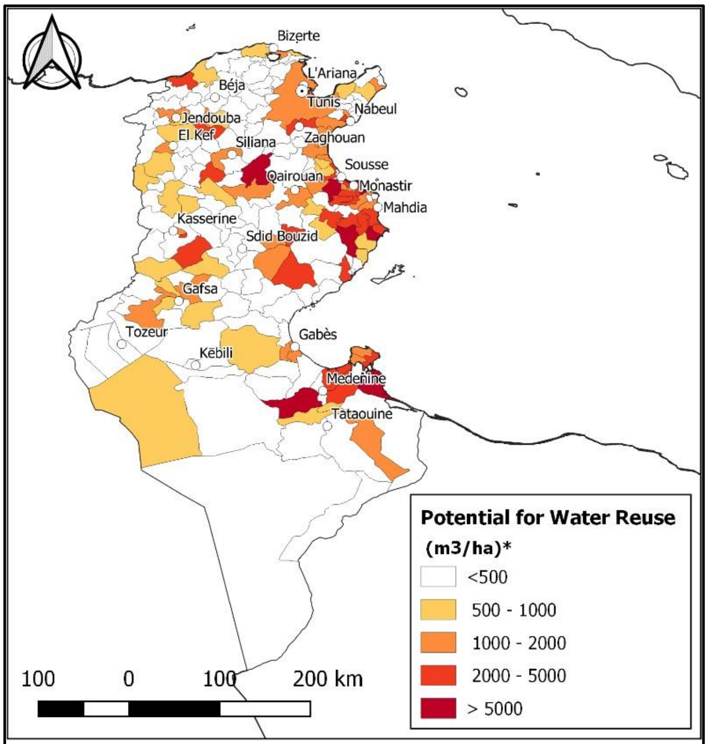
Water resources in Tunisia are characterized by scarcity and pronounced seasonal and yearly variations. Exploitation of conventional water resources is very advanced and it is expected that water demand, driven by population increases, urbanization and improvements in living standards could reach its maximum around the year 2030. Over the last decade, Tunisia has achieved considerable success in expanding access to both water and sanitation services, but challenges remain (World Bank 2014b; Ameur 2007) (World Bank, 2014; Horchani A., 2007).

2.3.3.1. Mapping of wastewater reuse potential for irrigation in Tunisia

The mapping of water reuse potential is reproduced from the deliverable 1.2 in the H2020 MADFORWATER project (Snethlage et al. 2018).

Overall, the situation in Tunisia appears more diverse in the possible combination of production potentials and agronomic centres that are more wide spread in Tunisia. Even the areas near Monastir offer a significant potential to reuse the wastewater from touristic centres and to irrigate high valuable crops in a highly intensive and surface minimizing way, whereas the seasonality of the wastewater availability according to the touristic peak seasons should be considered (see Figure 20).

From the logistic perspective the priority areas to intensify the production of high value crops should be the area of Nebeul (73 100 inhabitants) at the south of the Cap Bon peninsula (see Figure 21). Within the inland, the surrounding of Kairouan (186,000 inhabitants) offers another interesting focus area. Both areas are in reasonable transport distances and offer own agro-logistic experiences.



*Calculations performed at distric level by dividing the total urban wastewater production by the irrigated area available

Figure 20: Tunisia current Wastewater production divided by irrigated area at district level

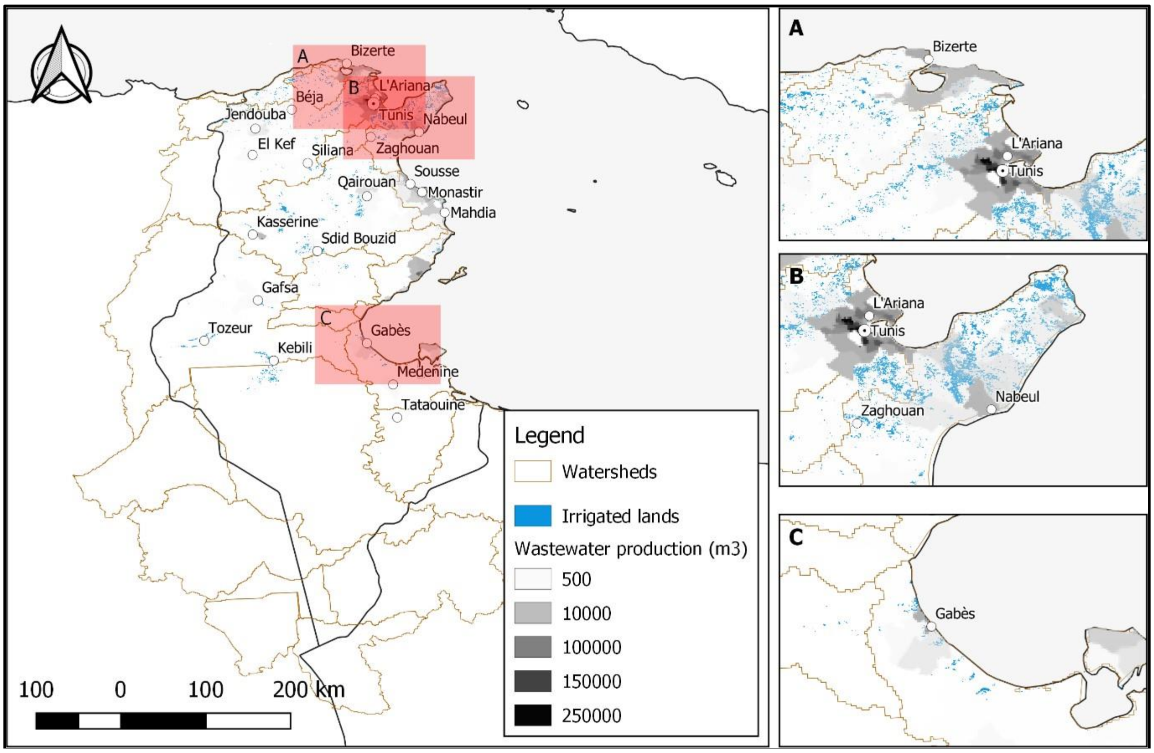


Figure 21: Tunisia current location of wastewater production hotspots and location of irrigated area

2.3.3.2. Water reuse options based on the DST-Assessment

The assessment presented in section 2.2.1, resulted in several options that could treat municipal wastewater (either typical raw wastewater or typical secondary effluent of existing WWTP) to the desired quality in order to comply with the corresponding regulation (either national or ISO). In order to select top-ranking options out of all the feasible ones, we proceeded to a ranking based on the lowest cost of treatment and resulted in four top-ranking scenarios for water reuse in Tunisia (Table 18).
From this ranking, we further selected two scenarios as building block for basin scale strategies presented further in this section. The two selected scenarios are highlighted in grey in Table 18. These are:

- **TU1**: Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops
  Technology suggested:
  No treatment necessary
- **TU2**: Reuse of municipal WWTP typical secondary effluent for irrigation (NT 106.03 standard)
  Technology suggested:
  Wetlands: Nicaragua

Table 18: Four top-ranking scenarios for water reuse in Tunisia based on lowest cost of treatment (treatment of 10,000 [m3/d])

Ranking	**Wastewater**	**End-use – water quality regulation**	**Technology**	**Cost of treatment** [USD/m^3]
1	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	No treatment	0
2	MAC - MWW - Typical Effluent Municipal Wastewater quality	Tunisian wastewater reuse regulation - NT 106.03 standard: irrigation	Wetlands: Nicaragua	0.15

Ranking	Wastewater	End-use – water quality regulation	Technology	Cost of treatment [USD/m³]
3	MAC - MWW - Typical Effluent Municipal Wastewater quality	Tunisian wastewater reuse regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use	Wetlands: Nicaragua	0.15
4	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Lagooning: Australia I	0.22

2.3.3.3. Water reuse option based on the MADFORWATER project pilot for Municipal Wastewater

- **TU3:** Reuse of municipal WWTP secondary effluent for irrigation. **Technology suggested:** MADFORWATER Pilot (Chotrana, Tunisia)

One possible treatment technology for MWW that has been developed within the MADFORWATER project is shortly described in the following section. The MWW treatment process consists of a train of multiple integrated treatment technologies, namely: (i) a nitrifying trickling filter that provides secondary treatment of organics and ammonia, (ii) a secondary settler for sludge sedimentation, (iii) a constructed wetland for heavy metals and remaining nutrients removal, (iv) a chemical disinfection unit and (v) an excess secondary sludge dewatering system.
The MWW treatment process was applied in two out of four MADFORWATER project pilot plants. The first pilot is located in Chotrana, Ariana, Tunisia and has a capacity of about 10 m^3/day, which projected results in an annual wastewater treatment potential of 3,650 m^3 in total. According to the analysis carried out by the decision support tool, the costs for the treatment of MWW amount to 1.03 TND/m^3 or 0.99 USD/m^3. The total annual MWW collected in the Cap-Bon Basin in 2016, where the pilot plant is located, amounts to 27.25 million m^3 (Office National de l'assainissement, 2016). Consequently, the pilot plant would be capable of treating 0.01% of the wastewater annually at a total cost of 3,760 TND or 3,614 USD. The expansion potential in this basin is therefore enormous. The results concerning the social aspects of the national-level conditions for water reuse assessment showed a positive result for Tunisia. This means that, according to the 2nd Arab State of Water Report (2012), 91.6% of the Tunisian population already uses improved sanitation services. Concerning the environmental aspects of the water reuse assessment, the results revealed a positive result for Tunisia in terms of a high compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guide.

2.3.3.4. Water reuse option based on the MADFORWATER project pilot for textile wastewater (TWW)

- **TU4:** Reuse of textile WW for non-food crops irrigation. **Technology suggested:** MADFORWATER Pilot (Gwash, Tunisia)

The current situation of textile wastewater treatment in Mediterranean African Countries is quite diverse. In Tunisia, some textile companies have already integrated internal wastewater treatment processes into their process sequences, aiming to reach up to 60% reuse of the treated sewage into the production processes. The remaining treated wastewater is discharged into the municipal sewage network. The TWW treatment process developed within the MADFORWATER project and applied in a pilot plant consists of the following treatment trains: (i) a coagulation / flocculation pre-treatment unit, (ii) a primary clarifier, (iii) an aerobic Moving Bed Biological Reactor (MBBR), (iv) a secondary clarifier, (v) a filter followed by dye adsorption on resins to further remove the remaining color, and (vi) a drying bed for sludge dewatering. The MADFORWATER pilot plant has been installed in the textile industry Gwash, located in the governorate of Korba (Nabeul, Tunisia), with a capacity of 10 m^3/day. According to the developed DST, the TWW treatment costs amount to 0.74 TND/m^3 or 0.71 USD/m^3. Extrapolated, the pilot plant is capable of treating up to 3,650 m3 per year. In the Cap-Bon basin where the pilot plant is located, a TWW volume of 450,000 m3 has been collected in the year 2016 (http://www.nabeul.gov.tn/fr/les-industries-manufacturieres/). Consequently, the pilot plant could treat 0.8% of the TWW at a cost of 2,700 TND or 2,590 USD. The results concerning the social aspects of the national-level conditions for water reuse assessment are the same as stated above since the assessment has been conducted on a national level. This also applies to the environmental aspect. Thus, 91.6% of the Tunisian population already uses improved sanitation services, and Tunisia has a high compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guide.

2.3.3.5. Barriers and measures to foster implementation

In Table 19 the detailed scored result, strategy excerpt, identified barriers and measures / (economic) instruments are shown. The scored results very between 1 (lower) to 3 (higher) for which different barriers were identified. These can be overcome by economic and non-economic instruments. The economic instruments include often price based measures. The non-economic include increase enforcement and capacity building in general and increase of number of treatment technology and MADFORWATER technologies.

Table 19: Tunisia's result of multi criteria analysis of different key questions, strategy excerpt, identified barriers and (economic) instruments. The results of the national-level conditions for water reuse assessment. 'Lower' national-level conditions for water reuse is in red and equivalent to the score '1', moderate national-level conditions for water reuse in yellow and equivalent to the score '2', 'higher' national-level conditions for water reuse in green and equivalent to the score '3'. Ts stands for Thematic subject. Ec stands for economy. WM stands for water management. P & I stand for policy and institution. L stands for legislation. S stands for society. En stands for environment. '-'stand for 'no data available' or 'not defined

Ts	Key question	Score detailed	Strategy excerpt	Identified barrier	Measures / instruments (economic)
Ec	-What is the **official financial development assistance** (gross expenditure) for water supply and sanitation?	2	Financial support is moderate	Restricted financial support	P2: Subsidies or other financial assistance (e.g. assisted loans)
	-What is the level of **economic water security**?	3	High water security	No	No
	-What is the **water pricing for agriculture**?	1	Moderate for water pricing	Costs of water pricing is too low to cover the actual costs	P1: Pricing/ water tariffs P3: Taxes
	-What are the **financial subsidies** for water use in agriculture?	2	Moderate financial subsidies	50% of costs are covered by governance for irrigation currently	P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes
WM	-What is the **transboundary water dependency ratio**?	1	Higher transboundary water dependency	High water supply dependency on neighbouring countries	P1: Pricing/ water tariffs P3: Taxes
	-What is the share of **produced volume** of industrial and municipal wastewater per total population in a country?	2	Moderate wastewater produced per total population	Moderate volume of wastewater to be treated per population	Q1: Quotas (command-and-control) Q2: Water markets/ water trading Non-economic instrument: Capacity building and technology scale up

Ts	Key question	Score detailed	Strategy excerpt	Identified barrier	Measures / instruments (economic)
	- What is the **share of treated to produced volume** of industrial and municipal wastewater?	2	High WW treatment potential available	Moderate share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology Non-economic instrument: Increase of number of treatment technology
	-What is the share of **harvested irrigated crop area per cultivated area**?	2	Moderate share of harvested irrigated crop area per cultivated area	Moderate level of control irrigation per cultivated area.	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology Non-economic instrument: Increase of MADFORWATER technology
P&I	-What is the **proportion of monitoring and reporting** system **in comparison to other countries**?	3	Higher proportion of monitoring in international context	No	No
	-What is the degree of **implementation of national monitoring and reporting** system?	3	Compliance with national monitoring and reporting system	No	No
L	- What is the **quality of contract enforcement, property rights, and the courts** in each country?	2	In international comparison: Moderate level of quality of contract enforcement, property rights, and the courts	Moderate level of quality of contract enforcement, property rights, and the courts	Non-economic instrument: Increase enforcement in general
	- What is the **regulation** for food and non-food crop irrigation with reclaimed water?	2	Partly compliance with legislation	Not allowed to irrigate non-food crop	Non-economic instrument: Adapt legislation
S	-What is the degree of **implementation of equitable water and wastewater tariffs**	2	Moderate degree of implementation of equitable water and wastewater tariffs	Limitations in the implementation of equitable water and wastewater tariffs	Increase enforcement in general
	-What share of population is using **improved sanitation services**?	3	Wide use of sanitation services	No, yet there is a large amount of treated WW that could be used for water reclamation	P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning for new technologies P3: Taxes for fresh water Non-economic instrument: Increase of number of treatment technology incl. MADFORWATER technolgoies
	-What is the **social acceptance** of a country towards water reuse for agriculture?	-	N/Av	N/Av	N/Av
En	-What is the status of **national water reuse regulations for irrigation** in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	3	Compliance	No	No
	- What is the share of the **area equipped for irrigation that has become salinized**?	3	Higher share of the area equipped for irrigation that has become salinized	No	No

2.4. Intermediate conclusions

This study presented in this chapter demonstrates the application of a decision support tool for water reuse to Egyptian, Moroccan and Tunisian case studies. Research of preliminary data identified key results on typical wastewater quality and current water quality regulations for water reuse. Some gaps were identified and missing parameters were complemented with values from international case studies to identify typical case studies that showed potential for water reuse implementation in Egypt, Morocco, and Tunisia.

For all defined case studies, adapted treatment trains that could treat wastewater to the desired quality at reasonable costs were identified and are presented in this deliverable. The results show that technological options are available for water reuse but the concept is not widely implemented in Egypt, Morocco and Tunisia.

The assessment indicated a high potential for water reuse in Egypt, Morocco, and Tunisia. In particular, Tunisia resulted with high water reuse level, followed by Egypt and Morocco. It showed that the policy context and social acceptance is favourable to the implementation of water reuse. The main barriers hampering implementation of water reuse were economic, water management and environmental thematic subjects.

The assessment is a positive step in improving the understanding of, and delivering a solution towards wastewater reclamation and reuse. The assessment expands the existing DST for an early-stage assessment from a broad perspective, which considers local technological and economic options from six different thematic subjects. This research's limitation is early-stage assessment with limited available data. This can be overcome by stating assumptions and ensure the assumptions are included while developing more in-depth statements. Consequently, the result of this research should be considered with limitations.

Future research into water reuse in North African and Mediterranean countries should (i) focus on specific case studies with high potential for water reuse and (ii) identify exemplary cases to implement demonstration sites for wastewater reclamation at an affordable cost.

Based on those case studies, we established exemplary basin-scale and national wastewater management strategies including economic instruments for Egypt, Morocco and Tunisia. We built the exemplary strategies upon the top-ranking options from the DST and from the MADFORWATER project pilot schemes. These options and corresponding technologies are complemented by the results of the multi-criteria decision analysis that identifies barriers, drivers and additional measures recommended to foster the implementation of sound solutions for water reuse in the region. In Table 20 the strategies results with costs and additional measures and barriers are presented as an overview and can be considered main outputs of the whole assessment presented in this chapter.

The results of potential measures that could overcome identified barriers shows three main types of measures. First, the price-based instruments are important to overcome the barriers. These include pricing/ water tariffs, remove subsidies or other financial assistance (e.g. assisted loans), and taxes. The underlying barriers is generally fresh water is available too cheap to cover the costs and thus became unattractive for irrigation. Second, base alike the first measure on price-based instruments: pricing/ water tariffs for fresh water and subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology. The underlying barrier is mainly not enough water is treated in comparison to available wastewater. Third, non-economic instruments are important with the additional measures as: increase enforcement and capacity building in general and increase of number of treatment technology and MADFORWATER technologies. The underlying barriers are mainly lack of awareness and knowledge, legislation and enforcement on wastewater reuse and further treatment facilities are required.

An additional key outcome of the assessment presented is the importance of the distribution costs, as demonstrated for the option **MO3**. The distribution costs were not considered for the other options but it can be stated that a judicious combination between the location of the wastewater source and the end-user location is crucial. Ideally, the potential reusers should be situated at a lower elevation than the source and the distance should be minimised. If reclaimed water has to be transported uphill after treatment for a long distance, the costs outreach greatly the treatment costs.

Furthermore, we recommend to consider a disinfection step before reusing water for crops irrigation, as this is a recurrent requirement in European and international guidelines for water reuse.

Table 20: Overview of the application of the DST and the pilot plant WW treatment type

Code	Description	Cost of treatment [USD/m³]	Additional measures and barriers to overcome for fostering implementation
EG1	Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops	**No treatment**	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:** Water is available too cheap to cover the costs and thus unattractive for irrigation of non-food crops **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Moderate share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:** Capacity building Technology scale up **Barrier III:** Lack of awareness and knowledge on wastewater reuse and further treatment facilities are required
EG2	Reuse of typical municipal wastewater for agriculture	0.39	**Additional measure I:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier I:**

Code	Description	Cost of treatment [USD/m³]	Additional measures and barriers to overcome for fostering implementation
	purposes in desert areas		Moderate share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure II:** Capacity building Technology scale up **Barrier II:** Lack of awareness and knowledge on wastewater reuse and further treatment facilities are required
EG3	Reuse of drainage Canal Water for irrigation	*Flow of 1,000 [m³/d]*: 0.51 *Flow of 10,000 [m³/d]*: 0.30	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:** Water is available too cheap to cover the costs and thus unattractive for irrigation **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Moderate share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:** Capacity building Technology scale up **Barrier III:** Lack of awareness and knowledge on wastewater reuse and further treatment facilities are required
MO1	Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops	**No treatment**	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:**

Code	Description	Cost of treatment [USD/m^3]	Additional measures and barriers to overcome for fostering implementation
			Water is available too cheap to cover the costs and thus unattractive for irrigation of non-food crops **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:** Increase enforcement and capacity building in general Non-economic instrument: Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge, legislation and enforcement on wastewater reuse and further treatment facilities are required
MO2	Reuse of typical municipal wastewater for irrigation of crops to be eaten raw	**No treatment**	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:** Water is available too cheap to cover the costs and thus unattractive for irrigation of crops to be eaten raw **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:**

Code	Description	Cost of treatment [USD/m^3]	Additional measures and barriers to overcome for fostering implementation
			Increase enforcement and capacity building in general Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge, legislation and enforcement on wastewater reuse and further treatment facilities are required
MO3	Specific case of M'Zar Wastewater treatment plant with multiple reusers.	**No treatment** **Distribution costs**: 2.21 (uphill elevation of 35m) 0.06 (downhill elevation of 25m) 1.19 (no evelation)	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:** Water is available too cheap to cover the costs and thus unattractive for irrigation of crops to be eaten raw **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:** Increase enforcement and capacity building in general Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge and enforcement on wastewater reuse and further treatment facilities are required
MO4	Reuse of municipal WWTP tertiary effluent for olive trees irrigation	**No treatment**	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:**

Code	Description	Cost of treatment [USD/m^3]	Additional measures and barriers to overcome for fostering implementation
			Water is available too cheap to cover the costs and thus unattractive for irrigation of crops to be eaten raw **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:** Increase enforcement and capacity building in general Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge and enforcement on wastewater reuse and further treatment facilities are required
TU1	Reuse of municipal WWTP typical secondary effluent for irrigation of non-food crops	**No treatment**	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:** Water is available too cheap to cover the costs and thus unattractive for irrigation of crops to be eaten raw **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:**

Code	Description	Cost of treatment [USD/m^3]	Additional measures and barriers to overcome for fostering implementation
			Increase enforcement and capacity building in general Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge, legislation and enforcement on wastewater reuse and further treatment facilities are required
TU2	Reuse of municipal WWTP typical secondary effluent for irrigation (NT 106.03 standard)	0.15	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:** Water is available too cheap to cover the costs and thus unattractive for irrigation of crops to be eaten raw **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:** Increase enforcement and capacity building in general Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge, legislation and enforcement on wastewater reuse and further treatment facilities are required
TU3	Reuse of municipal WWTP secondary effluent for irrigation	*Flow of 1,000 [m^3/d]*: 1.25 *Flow of 10,000*	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:**

Code	Description	Cost of treatment [USD/m³]	Additional measures and barriers to overcome for fostering implementation
		[m³/d]: 0.59	Water is available too cheap to cover the costs and thus unattractive for irrigation of crops to be eaten raw **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:** Increase enforcement and capacity building in general Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge, legislation and enforcement on wastewater reuse and further treatment facilities are required
TU4	Reuse of textile WW for non-food crops irrigation	*Flow of 200 [m³/d]*: 1.60 *Flow of 1,000 [m³/d]*: 0.89 *Flow of 10,000 [m³/d]*: 0.45	**Additional measure I:** P1: Pricing/ water tariffs P2: Remove subsidies or other financial assistance (e.g. assisted loans) P3: Taxes **Barrier I:** Water is available too cheap to cover the costs and thus unattractive for irrigation of crops to be eaten raw **Additional measure II:** P1: Pricing/ water tariffs for fresh water P2: Subsidies or other financial assistance (e.g. assisted loans) at the beginning of new technology **Barrier II:** Lower share of treated WW to produced volume, meaning potentially not much water is treated in comparison to available WW **Additional measure III:**

Code	Description	Cost of treatment [USD/m^3]	Additional measures and barriers to overcome for fostering implementation
			Increase enforcement and capacity building in general Increase of number of treatment technology and MADFORWATER technologies **Barrier III:** Lack of awareness and knowledge, legislation and enforcement on wastewater reuse and further treatment facilities are required

3. Strategies and economic instruments for water reuse and water & land management in agriculture (Task 5.3: UPM)

3.1. General structure of the DST

This section corresponds to section 2.1.2 of MADFORWATER Final report on the water & crop allocation model, Deliverable 3.4. (MADFORWATER, 2019c)

The general objective of the DST (agro-economic model) is to develop water and land management strategies aimed at an optimal exploitation of the irrigation technologies and at the assessment of the impact of economic instruments for improving irrigation efficiency and for enhancing treated WW reuse in agriculture.

A general structure of the DST has been framed to be comprehensive and flexible in order to be able to include all the possible specificities of the three case studies and to incorporate different types of crops, intensification levels, use of fertilizers, as well as different types of water sources. The general structure of the agro-economic model can be illustrated as follows:

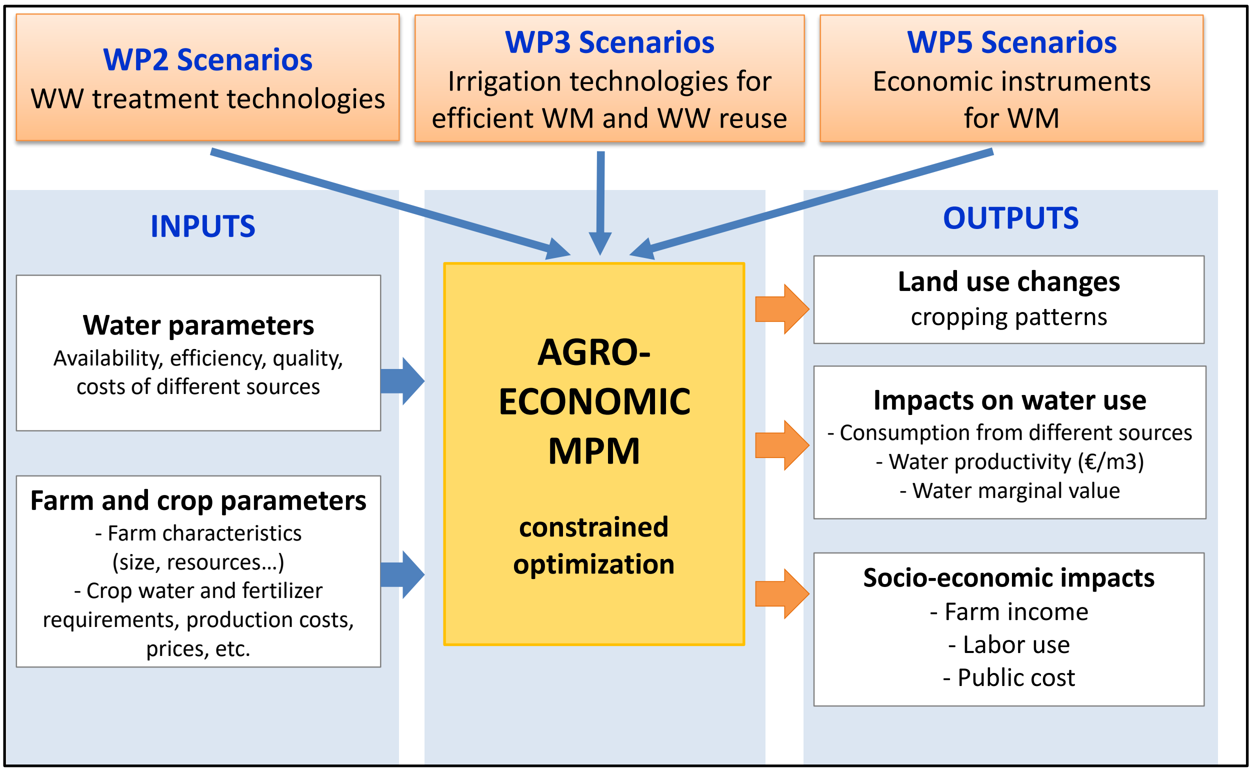


Figure 22: general structure of the Agro-economic model

The agro-economic model is written in GAMS (General Algebraic Modeling System) language. It is based on a mathematical programming of a farm model widely applied in the economic-agricultural analysis and in the irrigated agriculture analysis. The objective of this model is to simulate farmers' behavior under different scenarios and risk situations. For each possible scenario, the proposed model allows to identify optimal farmers' choices related to cropping patterns and agro-techniques. The model

also allows to estimate the effects of such choices on water consumption, water distribution among crops, land use changes and farmer income.
The agro-economic model maximizes farmers' utility subject to a set of resources (land and water), agronomic and economic constraints, and offers the possibility to simulate and analyze different scenarios. It aims at the identification of the optimal cropping pattern of the study area and the calculation of the relative water demand.
The objective function of the model maximizes farmers' utility defined as the expected revenue minus its standard deviation due to risk averse towards price/yield variation.

$$MaxU = Z_p - \phi * \sigma(Z_p) \quad (1)$$

where
U: Utility to be maximized
Zp: Average (expected) farm revenue (€)
ϕ: Risk aversion coefficient
σ: Standard deviation of the expected income (€)
p: farming type/position

The farm revenue per farm type, Zp, is defined as the difference between the value of production and variable and fixed costs, except for the cost for the irrigation and the cost of fertilizers. Where it is relevant, as in the Egyptian case, also a specific cost for energy is included.
It is given by the following equation:

$$\begin{aligned} Z_p = & \sum_{c,i,q,} Pr_c * Y_{c,q} * X_{c,iq,p} - Vcost_c * X_{c,i,q,p} \\ & - Fcost - (Fertreq_{q,f} * Fertpr_f) - PrWat_q * QWat_{q,p} - TarWat_q * irrland_q - EnCon_p * DrWat_p \end{aligned} \quad (2)$$

where
c: crops
q: type of water
i: irrigation technique
f: type of fertilizer
$\mathbf{X_{c,i,q,p}}$: the crop activity level (ha)
$\mathbf{Pr_c}$: average crop price (€/ql)
$\mathbf{Y_{c,q,t}}$: crop yield (ql/ha)
$\mathbf{Vcost_{c,t}}$: variable costs (€/ha)
Fcost: fixed costs (€)
$\mathbf{Fertreq_{c,q,f}}$: amount of fertilizer (kg)
$\mathbf{Fertpr_f}$: fertilizer price ((€/kg)
$\mathbf{PrWat_q}$: water tariff per m3 or per type of water
$\mathbf{QWAT_{q,p}}$: annual used water (m3) per type of water
$\mathbf{TarWat_q}$: water tariff per ha and per type of water
$\mathbf{Irrland_{q,p}}$: irrigated land (ha) by type of water
DrWat: drained water
EnCon: energy required (KwH/m3)

The value of production refers to the product sold for final consumption or processed. Variable costs are given by the specific cropping expenses including costs for temporary labour and mechanization, seeds, fertilizers and pesticides, hire charges, fuel, insurance, electricity, etc.).
Costs of irrigation water are not included in the variable costs since they are an endogenous variable. They have been defined in two ways: i) as the volume of water used multiplied by the price of water per cubic meter and/or ii) as a fixed water tariff to be paid for each hectare of irrigable land or for total agricultural land.
Risk is present in all management decisions of agricultural systems, as a result of price, yield and resource uncertainty and the risk aversion coefficient (ϕ) measures the degree of risk aversion of the agent. This coefficient is related to the farmer and its value is often ranging from 0 to 1.65. If ϕ=0 implies farmer is risk neutral, as the risk aversion coefficient increases the diversification of cropping pattern increases.
σ , standard deviation of farm income (€) is given by the following:

$$\sigma(Z) = \sqrt{\sum_k \frac{(Z - ZK_{sn,sm})^2}{N}} \qquad (3)$$

where
ZK: the random income (€)
N: number of states of market for price/yield variability (N=50)
Z: expected farm income (€)
sn: states of nature
sm: state of market

The random income Zkk is calculated using the same equation applied for calculating the expected income Z; the unique difference was that the average price/yield are replaced, by the random price/yield over state of nature (k) where price_kc,sm and yield_kc,sn are vectors of independent random numbers normally distributed (i.e. they are calculated using a normal distribution function based on the average and the standard deviation of price and yield).

Water and fertiliser use, WATused and FERTused, are defined by specific equations as follows:

$$WATused_{q,p} = \sum_{c,i}\left(\frac{NIR_c}{htech_{i,p}}\right) \cdot X_{c,i,q,p} \qquad (4)$$

$$FERTused_{f,c,q} = \sum_{c,i,p} fertreq_{f,c,q} * X_{c,i,q,p} \qquad (5)$$

Where:

- **NIR:** net irrigation requirements of crops(m3/ha)
- **htech**: technical efficiency of irrigation system
- **fertreq**: amount of fertiliser for each crop(Kg/ha)

Farmers' decision is clearly constrained by numerous factors such as quantity and quality of input, mainly land and water, water policies, and are made subject to an often considerable uncertainty (yields, prices, costs, resources. The main constraints adopted by the model include:

Agricultural **land constraint**: imposes that the total land requirement for cropping cannot exceed agricultural land availability.

$$\sum_{c,i,t,q}\left(Luse_{c,m} \times X_{c,i,q,p}\right) \leq Land\ (p) \quad (6)$$

Where
L use$_{c,m}$: Land occupation coefficient for each crop per month;
m: Month
Land$_p$: Agricultural land availability in the different field section (ha).

The total land constraint imposes that the set of crops grown, including uncultivated land and no-tillage, doesn't exceed the available land; it is defined on monthly basis through setting up a production schedule that specifies the land use per crop.
The Water constraints imposes that the sum of water requirement for irrigated crops over the year cannot exceed the yearly water availability:

$$WATused_{q,p} \leq WATav_{q,p} \quad (7)$$

where
WATav$_{q,p}$: Water availability(m3).

When different water quality and/ or source are considered, several constraints are included.

3.1.1. DST applied to Egypt

3.1.1.1. The case study of Kafr-El Sheikh

The Egyptian case study refers to the irrigated farming system in Kafr-El-Sheikh region in Northern Egypt with a total population of about 3 million inhabitants. El Wasat command area, located in the northern part of Kafr-El -Sheikh and supplied from Mit Yazeed main canal, was selected for the study. Mit Yazeed canal is 63 km long and feeds 19 branches for a total area of 88,200 ha.

Property and responsibility for operation and maintenance of canal and sub – branch canal are public. The public sub-branch canal delivers water to private channels called "Mesqas". Each Mesqa serves an area of about 20 to 83 hectares. Mesqas feed farm ditches called "Marwas". Each Marwa serves up to 8.3 hectares. Operation and maintenance of Mesqas and Marwas are done by the water users and/or Water Users Associations.

The Irrigation Improvement Project (IIP) enabled the operation of Daqalt canal on a continuous flow through automatic downstream control gates with aim to guarantee greater flexibility in the timing of

irrigation applications, as compared to the rigid rotation schedules of the traditional system, in order to meet crop water requirements. The flow in the branch canal is determined by regulation of the discharge at the head of the canal and accounts for the area served by the canal and the cropping pattern. The former rotational system resulted in inefficient application of irrigation water, water losses, and an inequitable water distribution but with IIP, water delivery services to the farmers improved and the flexibility of the water management system increased. However, this improvement program did not solve the problem of inequity of water availability between head and tail areas along the branch canals. To represent all the agricultural area in the Mit Yazeed main canal, six sample tertiary canals were selected in the head, middle and tail of the Daqalt sub-branch canal which is an earthen branch canal located at km 41 of Mit Yazeed on the right side, 11.42 km long and serving a total of 2,344 ha (Abdelmoneim, 2016).
During a fieldwork carried from February to April 2016, several sites and institutions were visited such as the Ministry of Agriculture and land reclamation, the Ministry of Water Resources and Irrigation (MWRI) and the National Water Research Centre. The different data sources were merged in the best possible way to ensure reliability and compatibility, even though the difficulty to unify data from different sources still remain a challenge. Where necessary, data have been updated in a second shorter field work dine during December 2018.

3.1.1.2. The model

The DST applied to the Egypt's case study reflects the general structure described above and in MADFORWATER, 2019c. However, in order to properly take into account case study's specificities, such as the differences existing in water availability and water distribution and application efficiency along the mesqa – index p in the equations and parameters - , the introduction of an innovative irrigation technology (the gated pipe) and the practice to reuse drained water, some variables and/or parameters have been modified as follows:

1) Given the multiple "external" constraints on farms and their decision-making process, which in Egypt contribute to determining the cultivation model, it was preferred to consider the decision concerning the allocation of land between the various crops among the various scenarios constant;
2) Fertilizer costs are included in the variable costs and not considered as separate;
3) The annualized investment cost of the technology of gated pipe and its O&M costs are considered in the fix and variable costs, respectively;
4) The amount of water drained and reused is calculated as the difference between the gross irrigation requirements of the cultivated crops and the water supply;
5) The cost to reuse the drained water is calculated and included in the equation of the farmers income. It is equal to the energy required, in kWh, to pump one cubic meter of water multiplied by the cost of the energy, in Euro/kWh.

The model, integrated and modified, was applied to the Egyptian case study to analyze alternative political scenarios and estimate the impacts of different policies in terms of parameters deemed relevant to the case study: amount of drained and returned water in the system, irrigation system performance in terms of adequacy economic performance of the farmers and, ultimately, the convenience and the effectiveness to adopt treatment and irrigation technologies developed in MADFORWATER.

3.1.1.3. Input data and Simulation Scenarios

- **Land and crop data**

According to the data provided by the National Water Research Centre, in the six selected Mesqas 348 farmers cultivate around 185 ha where 75 ha are in head position, 50 ha in the middle and 59 ha in the tail of the canal. As in all the North Delta, two seasons are differentiated in the selected Mesqas: summer season (mid of March-mid of September) and winter season (October-February). Main summer crops are rice, cotton and maize. In the winter season, alfalfa, wheat and sugar beet are the dominant crops. Farmers usually divide their land holdings into thirds, rotating between cereals and break crops. Popular winter-summer rotations include the following: wheat followed by rice, and wheat or alfalfa followed by maize (FAO, 2015).

Table 21: Cropping pattern in the selected Mesqa, Egypt

			WINTER				SUMMER		
Canal	Position	Meska Code	Alfalfa	Wheat	Sugar Beet	Other	Cotton	Rice	Maize
Daqalt	H	MD01	45.81%	38.87%		15.32%	41.64%	55.52%	2.83%
		MD02	37.09%	56.62%		6.29%	42.52%	42.52%	14.96%
	M	MD03	24.37%	33.41%		42.22%	29.63%	59.26%	11.11%
		MD04	40.46%	30.51%		29.12%	33.36%	64.87%	1.85%
	T	MD05	43.99%	30.72%	4.42%	20.87%	27.21%	54.42%	18.37%
		MD06	17.04%	37.78%		45.19%	23.85%	69.93%	6.22%

Source: NWRC

Crops yields' data have been collected and used to obtained the average yield and its variability.

Table 22: Crop Yields, Egypt

ton/ha	2007	2008	2009	2010	2011	2012	2007-'12	2013
Cotton	16.2	12.9	14.3	12.5	16.8	12.6	14.2	11.6
Maize	8.7	8.2	8.2	9.0	8.9	8.7	8.6	8.7
Rice	10.0	9.8	9.4	9.2	9.4	9.1	9.5	8.9
Wheat	6.7	6.4	6.4	6.4	6.4	6.4	6.4	6.3
Alfalfa	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Vegetables	n.a	34.9	34.8	32.9	n.a.	32.5	33.8	34.3
Sugarbeet	50.8	49.3	48.7	47.5	47.6	48.0	48.6	47.8

Source: Agricultural Statics in Kafr El Sheikh, Economic Affairs Sector, MALR, various years

Finally, cost of production and domestic prices data have been collected.

Table 23: Cost of production, Egypt

Direct costs, Euro/ha	
Cotton	532
Maize	467
Rice	489
Wheat	419
Alfalfa	n.a.
Vegetables (Potatoes)	1 003

Table 24: Prices of products, Egypt

Price, Euro/ha	
Cotton	971
Maize	157
Rice	240
Wheat	209
Alfalfa	512
Vegetables (Potatoes)	209

Sugarbeet	929

Source: CFC, 2016

Sugarbeet*	34

Source: MALR

- **Water data**

Irrigation permits double and even triple cropping on most of the arable land and enabled farmers to switch the crop rotation from a three- to a two-year cycle. Irrigation method applied for all crops except for rice, is the traditional surface irrigation with an irrigation efficiency that can be estimated around 60%. For the paddy system used to cultivate rice, the irrigation efficiency is 50%. Available water per season and per position of the Mesqa in the sub-branch canal highlights relevant differences.

Table 25: Available water per season and per position of the Mesqa, Egypt

Water Supply (m3)	Summer	Winter	Total
Head	1 052 770	390 050	1 442 820
Middle	721 053	230 405	951 458
Tail	675 714	218 502	894 216
Total	2 449 537	838 957	3 288 494

Source: our elaboration on NWRC

Table 26: Net Irrigation requirement per crop, Egypt

WINTER								SUMMER					
Alfalfa		Wheat		Sugarbeet		Vegetables		Cotton		Rice		Maize	
Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha	Date	mm/ha
15/1	120.3	**15/1**	45.3	**15/10**	40.3	**15/10**	40.8	**15/03**	56.0	**15/05**	60.3	29/5	54.6
30/1	15.5	**30/1**	29.3	**30/10**	20.5	**30/10**	36.3	**30/03**	36.0	**30/5**	71.4	13/06	42.9
15/1	20.4	**15/1**	27.3	**15/11**	20.2	**14/11**	36.0	**14/04**	44.9	**14/06**	84.7	28/06	54.5
30/1	22.0	**30/1**	27.4	**30/11**	22.1	**29/11**	36.5	**29/04**	59.8	**29/06**	96.2	13/07	75.2
14/01	21.8	**14/1**	28.8	**15/12**	24.3	**14/12**	27.2	**14/05**	80.1	**14/07**	86.0	28/07l	93.3
29/01	23.3	**29/01**	32.0	**30/12**	26.5	**29/12**	25.0	**29/05**	100.0	**29/07l**	84.8	12/08	89.3
13/02	27.5	**13/02**	38.5	**14/01**	29.9	**13/01**	24.4	**13/06**	98.5	**13/08**	82.6	27/08	85.6
28/02	32.2	28/02	46.1	**29/01**	29.4	**28/01**	25.1	**28/06**	101.9	**28/08**	79.7	11/09	80.5
15/03	39.0	15/03	47.8	**13/02**	34.7	**12/02**	28.2	**13/07**	99.3	**12/09**	69.6	26/09	71.1
30/03	45.0	30/03	55.2	**28/02**	40.8			**28/07**	97.0	**27/09**	48.9	01/10	
14/04	45.9	14/04	64.3	**15/03**	48.8			**12/08**	88.9	**29/09**			
29/04	36.7	29/04	60.6	**30/03**	55.0			**27/08**	73.7				
1/05		14/05	36.9	**14/04**	57.8			**11/09**	59.3				
				29/04	54.1			**26/09**	43.7				

Source: our elaboration on Abdelmoneim data, 2016

Efficiency changes along the sub-branch canal according to the position of the mesqa as given in the following table

Table 27: System irrigation efficiency, Egypt

Efficiency	
Paddy.Head	55%
Paddy.Middle	50%
Paddy. Tail	45%
Furrow.Head	65%
Furrow.Middle	60%
Furrow. Tail	55%

- **Simulation Scenarios**

The baseline scenario

The baseline scenario corresponds to the current situation in the studied region. In this scenario, 17 787 m3/year/ha of water are provided as an average (Table 25) where 19 310 m3/year/ha, 18 670 m3/year/ha and 15 100 m3/year/ha are the amount of water provided in the different sections of the mesqa. Water distribution and application efficiency changes, for each different irrigation method, along the sub-branch canal according to the position of the mesqa – head, middle, and tail section - as given in the following: Paddy.Head 55%, Paddy.Middle 50%, Paddy. Tail 45%, Furrow.Head 65%, Furrow.Middle 60%, Furrow. Tail 55%. The price of the energy used by the farmers to pump the drained water into the system is equal to 0.061 Euro/kWh.

By changing one or more factor, different scenarios can be obtained:

The technology scenario

In this scenario, a new irrigation technology - the gated pipe - is proposed.

Gate pipe is a new type of high flow calibrated nozzle able to provide constant discharges as pressure decreases: self-compensating gated outlets minimizes each pressure variation and maintain constant outlet discharges within a certain operating range. The main objective to develop such technology is to increase the distribution uniformity of water applied at farm level and, therefore, to reduce the amount of water going to the drainage system in favor of more clean water available at the upstream irrigation canals.

Figure 23: Self-compensating gated pipe system

The annualized cost of the equipment is estimated to 232 Euro for each hectare of irrigated land equipped with the new technology while an additional cost of 145 Euro/year for the O&M is estimated compared to the traditional irrigation system currently used. Both the costs of investment and operation&maintenance have to be paid by the farmers. The effect of the new technology appears in the efficiency of the irrigation system: a uniform efficiency of 0.75% is considered along all the sub-branch canal for the furrow irrigation; nothing changes for the paddy method. The price of the energy is set equal to 0.061 Euro/kWh. In combination with the 'water availability scenario' (see below), decreasing quantities of water supplied to farmers are also simulated.

The water availability scenario

In this scenario, the quantity of water supplied to farmers can be gradually reduced in combination with the efficiency gains achieved in the 'technology scenario' thanks to the introduction of the gated pipes. A uniform reduction of 10% along all the mesqa has been simulated and price of the energy is set equal to 0.061 Euro/Kwh.

The policy scenarios

In this scenario, given both the introduction of the innovative gated pipe (with the associated costs and efficiency gains) and the reduction in the water supply: an innovation subsidy policy is simulated to cover all or part of the gated pipe equipment and O&M costs. Further, an energy pricing policy is also simulated by increasing the current price for electricity.

3.1.2. DST applied to Morocco

3.1.2.1. The case study of the Citrus sector in Souss Massa basin

Souss-Massa is one of the twelve regions of Morocco. It covers an area of 51,642 km² and it has a population of 2,676,847 as of the 2014 Moroccan census. The capital of the region is Agadir. Agriculture is the most important economic activity in the region; Souss Massa is in fact considered a leading region in the production of several fruit and vegetable crops such as tomato and citrus.

The model was applied to the citrus production system that occupies an area of 40343 ha which represents one third of the total citrus area in Morocco. 30 % of farms have an average farm area of more than five hectares and represent 99 % of the total area. Their prime objective is the economic profit; this objective determines the management strategies of their activity.

To achieve the maximum profit, farmers choose carefully the varieties and the rootstocks to be planted. The choice of the variety is based on its productivity, response to stress, resistance to certain diseases and market demand.

The most used varieties in the region are Clementine (31%), Maroc late (22%), Navel, (12%), Nour (12%), Nadorcott, Ortanique and Salustiana cover the remaining part. Farmers rely on external labor, permanent and seasonal, which is generally paid every two weeks. Through the years, farmers in the study region have developed ways to organize their activities, and so they have created cooperatives, each of which combines a number of farmers. This form of organization allows farmers many advantages, such as technical consultancy, assistance with irrigation, fertilization and phytosanitary treatments, and commercialization of the produce to the international market. Once collected, the product is packaged and sent to the markets of destination according to the demand. Cooperatives in the region deal mostly with the European Union, Russia, China and the United States of America. These markets require some specifications and directives (such as Global Gap, BRC …) which impose certain hygiene and sanitation instructions through the whole production chain (nurseries, farms, transport means and packaging factories). Cooperatives assist farmers also in the implementation of these directives, and periodic audits are carried out to insure the respect of these instructions.

3.1.2.2. The model

The DST applied to the Morocco's case study reflects the general structure described above and in MADFORWATER, 2019c. However, to properly take into account the availability of a larger amount of wastewater of water of different qualities by using the treatment and irrigation technologies proposed and tested in the framework of the MADFORWATER project, some variables and/or parameters have been modified as follows:

1) The proper irrigation and fertilization strategy with the use of treated wastewater been included in the model based
2) Possible impacts on crops yield associated with the use of treated wastewater have been explicitly considered
3) Fertilizers costs have been excluded from the variable costs since they are the parameters that will allow the comparison between the two water quality resources (fresh water and treated wastewater) and separately considered in the farmer's income equation.

The model, integrated and modified, was applied to the Moroccan case study to analyze alternative political scenarios and estimate the impacts of different policies in terms of parameters deemed relevant to the case study: the optimal allocation of land and of different quality irrigation waters among crops will be identified economic performance of the farmers and, ultimately, the convenience and the effectiveness to adopt treatment and irrigation technologies developed in MADFORWATER.

3.1.2.3. Input data and Simulation scenarios

- **Water data**

Due to the exhaustion of local aquifers, farmers rely on surface water for a part of their irrigation needs. Water is delivered from nearby dams, for an average price of 0.15 Euro/m3. This tariff does not vary according to the volume of water consumed, and there is no fixed tariff applied for each unit of cultivated land. Each farm is equipped with a storage basin, in order to store water coming from the dam to be used when needed.

In order to manage the irrigation and fertilization procedures, farmers are requested, by the cooperative, to do soil and water analysis at the beginning of the year, in addition to leaf analysis during the growing cycle. In addition to that, and on a daily basis, farmers receive text messages on their mobile phones, with climate parameters (ETo, humidity, temperature) to help them determine the amount of water to be applied for the irrigation event. To maximize water efficiency, all farms are equipped with drip irrigation systems. The model however defines a set of irrigation techniques (surface, sprinkler and drip irrigation). The efficiency for drip irrigation systems is set to 95%.

The net irrigation requirements have been calculated from the data collected from the study area for the five citrus chosen varieties. NIR are supposed not to change among the fresh and treated wastewater. In the area, the wastewater is treated in the treatment plant to a tertiary level using Ultra Violet rays, which requires the use of technology and energy, and thus, the treatment cost is higher, equal to 0.23 Euro/m3.

Table 28: Annual water requirements (mm) for selected varieties on a fortnightly basis, Morocco

Crop	jan1	jan2	feb1	feb2	mar1	mar2	apr1	apr2	may1	may2	jun1	jun2
Clementine	14	14	24	21	24	26	28	28	32	34	33	48
Navel	14	15	23	20	23	25	31	31	31	33	32	46
Maroc Late	14	15	26	23	26	28	35	35	35	38	37	53
Nour	13	14	24	21	24	26	28	28	32	34	29	42
Nadorcott	27	28	9	7	22	35	40	45	52	63	65	51
	jul1	jul2	aug1	aug2	sep1	sep2	oct1	oct2	nov1	nov2	dec1	dec2
Clementine	37	40	32	34	16	16	13	14	14	14	9	13
Navel	46	49	41	43	23	23	19	22	21	21	8	12
Maroc Late	53	56	47	50	24	24	19	22	21	21	8	13
Nour	33	35	28	30	16	16	13	15	14	14	8	13
Nadorcott	60	76	74	80	76	74	49	45	35	17	4	18

- **Crop data**

Yields per variety, during the period of 2016/2017 for the normal irrigation -100 % (Crop evapotranspiration) ETc -, prices at which crops are sold in the international market, along with their standard deviations and variable costs of production - including external labor for required during the production cycle to perform farming tasks, inputs (seeds, treatments) and machinery and excluding fertilizer and water that have been considered as separated – have been collected from the cooperative in charge for product commercialization, official websites of authorities responsible for exports (EACCE) and the FAO statistics website (FAOSTAT).

Tables Table 29, Table 30,Table 31 and Table 32 show the yields per variety for the study region, during the period 2016/2017 for the normal irrigation (100 % ETc) and the prices at which crops are sold in the international market, along with their standard deviations. These data were collected from the cooperative in charge for the product commercialization, official websites of authorities responsible for exports (EACCE) and the FAO statistics website (FAOSTAT).

The major part of production variable costs is represented by the transport and collection of fruits (26%).

Both water and fertilizers costs have been excluded from the variable costs since they are the parameters that will allow the comparison between the two water quality resources (fresh water and treated wastewater). Due to its richness in some fertilizing elements, the use of treated wastewater could allow to reduce the amount of fertilisers.

The annual requirements of two key fertilizers (Ammonitrate and Mono Ammonium Phosphate MAP) for the five varieties are presented in the table. Nitrogen is supplied to the plant in the form of Ammonitrate, which contains 33 % of N. Phosphorus is supplied in the form of MonoAmmonium Phosphate (MAP), containing 62 % of P2O5. The two fertilizers are sold in the market at 0.32 and 0.89 Euro/kg for Ammonitrate and MAP, respectively.

Table 29: Crop Yields, Morocco

Variety	Yield (t/ha)
Clementine	30
Nadorcott	25
Navel	40
Maroc Late	45
Nour	40

Table 30: Variable costs, Morocco

Variety	Variable costs (Euro/ha)
Clementine	4 800
Navel	5 000
Maroc Late	5 000
Nour	4 900
Nadorcott	4 740

Table 31: Fertilizers' requirements,

Crop	Ammonitrate (Kg/ha)	MAP (Kg/ha)
Clementine	570	68
Navel	603	77
MarocLate	612	78
Nour	571	65
Nadorcott	558	73

Table 32: Crop prices, Morocco

Variety	Yield (t/ha)
Clementine	30
Nadorcott	25
Navel	40
Maroc Late	45
Nour	40

- **Simulation Scenarios**

<u>The baseline scenario</u>

The baseline scenario corresponds to the current situation in the study region. In this scenario, only fresh water is available for farmers in a sufficient amount (8000 m3/year/ha). The price of fresh water is equal to 0.15 Euro/m3 with an efficiency of the drip irrigation system equal to 95%.

By changing one or more factor, different scenarios can be obtained:

<u>The water availability scenario</u>

In this scenario, the treated wastewater is an additional irrigation water source made available by the innovative technologies proposed and tested by the MADFORWATER project (MADFORWATER, 2019a). Both fresh water and wastewater, with their current prices are considered: price of wastewater 0.23 Euro/m3 and price of fresh water 0.15 Euro/m3. The efficiency for the system is equal to 0.85 for

wastewater, and 0.95 for fresh water. The efficiency is considered lower in the case of wastewater, due to the lower quality of this resource. Such lower quality affects the functioning of the system by clogging and salts accumulation on pipes. The Safe Irrigation Management (SIM) model was used in order assess irrigation and nutrient requirements, crops'yields and soil quality in terms of soil salinity under treated wastewater irrigation (MADFORWATER, 2019b).
Given the characteristics of the TWW and their nutrient content, crops fertilizer requirements are totally satisfied by using this additional irrigation water source. However, the strict use of TWW induces an average yield decrease of 8%, mainly due to the negative impact of the increase of salinity level in the root zone.

The policy scenarios
In this scenario, given the availability of both fresh and treated water and their associated levels of efficiency, 0.95% and 0.85%, respectively, a water pricing policy is simulated by taking constant the price for freshwater (0.15 Euro/m3) and decreasing more and more the price of treated wastewater starting from its current level of 0.23 Euro/m3 to 0.08 Euro/m3.
Also, in combination with the 'technology scenarios' (see below), a public subsidy to the farmer to cover the cost of the innovative calibrated nozzle is also simulated.

The technology scenario
In this scenario, given the availability of both fresh and treated water and their prices, 0.15 Euro/m3 and 0.23 Euro/m3, respectively, a new technology – the innovative calibrated nozzle adapted to the irrigation with treated wastewater - was proposed with an annualized cost (including investment costs for nozzle, pumps and pipes and O&M costs such as cleaning solvent and electricity) estimated in 350 Euro/ha. The effect of the new technology appears in the efficiency of the irrigation system: an application efficiency of 0.95% is considered.

3.1.3. DST applied to Tunisia. Knowledge base: Statistical and fieldwork analysis

3.1.3.1. The case study of Nabeul (Tunisia)

Nabeul is a coastal governorate in north-eastern Tunisia surrounded by the Mediterranean Sea, except the south west side where it is delimited by the three governorates Zaghouan, Sousse and Ben Arous (figure 23). The region of Nabeul covers an area of 2822 km², which represent 1.8% of the country's surface. Nabeul is characterized by a semi-arid Mediterranean climate with mean annual values of precipitation, temperature, and potential evapotranspiration of about 450 mm, 20°C and 1300 mm, respectively.

The population of Nabeul governorate amounted 787,920 inhabitants in the year 2014 (INS, 2019). Population is mostly urban with a rate of urbanization of 67 % (INS, 2019). Agricultural areas dominate the entire region. With 3 % of the agricultural area of Tunisia, Cap Bon (Nabeul) represents 16% to the nation's total agricultural production. Besides the importance of the region's production in terms of quantity, Nabeul is known by several crop cultivations. In fact, the region accounts for 85% of the national citrus production, 63% of the national tomato production, 97% of the national strawberry production and 40% of the vine products. The governorate also accounts for 712 industrial enterprises, particularly in the transformation of agricultural products (tomato, vine ...) (Ministry of agriculture, 2018).

Water scarcity is considered the main problem faced by farmers in Nabeul. Then, it is important to look for solutions for the adaptation of the Nabeul agricultural sector to cope with water scarcity and to provide recommendations on how to reduce the effects of water scarcity based on some scenarios development.

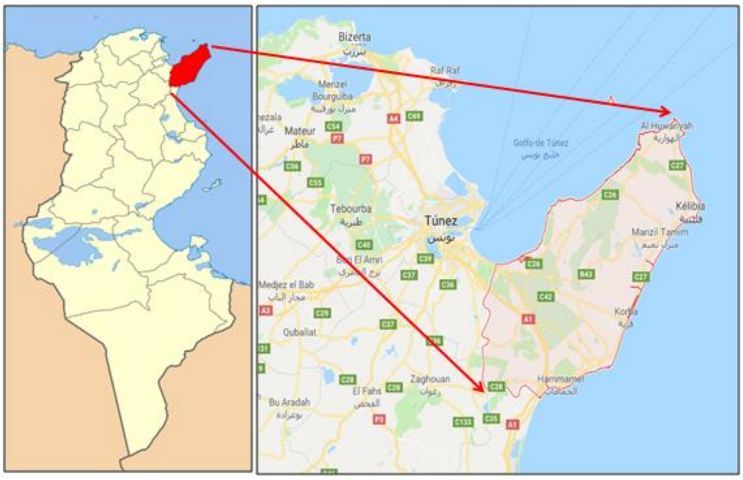


figure 24: localization of Nabeul governorate, Tunisia case study

3.1.3.2. Fieldwork analysis and creation of a knowledge base

The development of the model and simulation scenarios is based on three fieldwork missions carried out in the region of Nabeul during 2018-2019 (Figure 25).

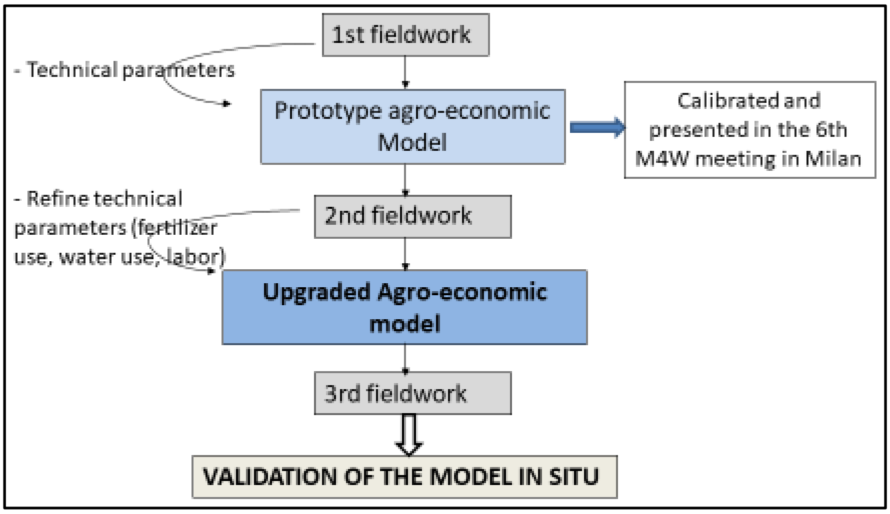


Figure 25: Model development steps based on the fieldworks

1st round: The first fieldwork took place in August 06th-29th, 2018. In total, 33 farmers from different delegations (Somaa, Grombalia, Beni Khalle and others) were surveyed to collect specific farm-level agro-economic information.

2nd round: In the second fieldwork (April, 22th-27th 2019) 17 farms were surveyed and several key institutions were enquired, such as the Ministry of Agriculture of Tunisia, the Regional Commissariat for

Agricultural Development (CRDA), and the Agricultural Development Groups (GDA). A more ample database was obtained to upgrade the model and simulate different water technologies and water management instruments. The results of the fieldwork also enabled us to refine the structural analysis of the region and to identify three region-based representative farms: F1 (3ha, vegetables,), F2 (2ha, citrus), and F3 (1.5 ha, citrus+olives). Characteristics of the representative farms are shown in the Table 33 Sources of water for irrigation have been considered. Specifically, farm F1 and F2 use conventional water sources (groundwater and surface water respectively) and F3 uses treated wastewater. Furthermore, they represent the average farms, with the most common crops present in the region of Nabeul. These are horticultural crops such as tomato, potato, pepper, and strawberry, and permanent crops such as olive trees for oil and citrus.

Table 33: Representative farm types in the Tunisia case study

Caracteristics	Representative farms		
	F1	**F2**	**F3**
Farm size (ha)	3	2	1.5
Irrigated area (%)	100	100	100
Weight (%)/ Nabeul	0.46	0.37	0.17
Total aggregated area (Nabeul) (ha)	21488	17490	7882
Water use (m^3/ha) - Winter - Summer	 3700 479	 2500 2000	 1000 1000
Water source	Groundwater	Surface water	TWW
Water Price (€/m^3)	0.04	0.04	0.02
Irrigation technique	Drip	Drip	Drip
Crop distribution (%)	Pep.int (20%) Tom.int(25%) Pot.ext(25%) Str.int (15%) Str.ext (15%)	Cit.int (50%) Cit.ext (50%)	Oli.int (67%) Cit.int (10%) Cit.ext (23%)

Source: Own elaboration based on fieldwork data and analysis

3rd round: In the third fieldwork (30th September to 2nd October 2019) 10 farmers were surveyed to validate the agro-economic model and obtain relevant information to build the simulation scenarios.

The surveys conducted are organized in different sections such as socio-economic, agriculture, and policies (see annex 2…). The main topics that are covered in the survey are: survey data (date, delegation and others), farmer data (name, age, gender, education level and others), land property data (area, land tenure regime, land sale, land rent and others), crop data (crops, area, sowing date, harvest date, risky crops and others), water data (water type, cost, applied quantity and others) and workforce data (number, gender, wage and others).

3.1.3.3. The model

The agro-economic model applied for the case study of Tunisia has been upgraded and some parameters have been included such as the level of crop intensification and water period, so as to take into account several elements such as:

1- The socio-economic effects of an increased amount of water obtained from improved treated wastewater reuse.
2- Continuous water flow obtained from the wastewater reuse, as surveyed farmers reported that the water supply is not permanent that affects the crop yield.
3- Reduction of irrigation losses resulting from the use of efficient irrigation technologies (calibrated nozzles) designed for treated WW reuse and adapted to the local climatic and socio-economic conditions.
4- Implementation of different economic instruments such as water quotas and water pricing to incentive farmers for using treated WW and for the adaption of innovative irrigation technologies. According to the fieldworks' results, surveyed farmers are generally reluctant to accept treated water so it is necessary to implement incentive economic instrument.

3.1.3.4. Input data

- **Water data**

Agricultural water management is mostly done by the Agricultural Development Groups (GDA, Groupe de Développement Agricole). The GDAs are responsible for equipping the irrigation perimeters where they intervene with basic agricultural and rural infrastructures and for supervising the activities of their members. GDAs are also responsible for charging water use.

In the region of Nabeul, there are three water types; Surface water comes from the Medjerda-Cap Bon canal and the dams of the region and is considered the most used water type. The Medjerda Cap Bon Canal plays a key role in the Nabeul agricultural sector. Most of the farms do not irrigate with groundwater due to high salinity that sometimes reaches up 8 g/l, except in some delegations like the delegation of Somaa that is known for the good quality of groundwater, where water comes from communal wells (salinity lower than 0.7 g/l). Treated wastewater is more concentrated in the delegation of Nabeul (Bir Romena, Messadi, Souhil) and is more used in the irrigation of fodder, tobacco and permanent crops such as olive and citrus. According to the fieldwork, the reuse of treated wastewater in agriculture is not fully accepted by farmers in the region, who have a negative perception of treated wastewater, because of its unsightly appearance (smell, color and other) and several farmers say that wastewater reduce the product's quality. Surveyed farmers said that they are facing a severe water scarcity, considering surface and groundwater together. In fact, farmers only cultivate part of the land in some of the plots due to the water scarcity.

The water price includes volumetric tariff and fixed tariff that includes fixed tax per hectare and subscription in order to constrain users to develop irrigation and to guarantee a minimum cost recovery. This price varies according to the type of water applied, the average water price of a cubic meter, in the irrigated public areas managed by the GDA, is 0.04 €/m3 for freshwater and 0.02 €/m3 for treated wastewater. According to the fieldwork, water prices are well accepted by farmers.

The Figure 26 shows an example of official invoice for irrigated perimeter of Souhil, in which the tariff is 50 DT (17 euro).

الجمهورية التونسية
مجمع التنمية الفلاحي بسوحيل

بطاقة انخراط لسنة ....

معلوم الصيانة : 20.000 د
معلوم الانخراط : 30.000 د

الإسم واللقب : ....
عدد بطاقة التعريف القومية : ....
رقم المجمع : ....

رئيس المجمع   أمين المال

Figure 26: official invoice

- **Land and crop data**

The main crops cultivated in the region are potato, tomato, pepper, strawberry and permanent crops such as citrus and olive. Most of the surveyed farmers have an area that varies between 1 and 5 ha, and cultivate more than 2 crops in this area. Characteristics of crops can be seen in Table 34.

Table 34: Characteristics of the main crops

Crops	Yield (kg/ha)	Price (€/kg)	Water requirement (m3/ha)	Variable cost (euro/ha)
Strawberry	42000	0.6	5000	11900
Potato	22000	0.2	3600	3200
Tomato	69000	0.06	5100	3300
Pepper	15400	0.27	3500	2500
Citrus	17000	0.34	4600	2700
Olive	8000	0.56	1500	1800

3.1.3.5. Simulation scenarios

The baseline scenario

The baseline scenario represents the current situation of the case study, i.e. the starting point for scenario simulations. In this scenario, water availability varies according to the type of farm, type of water (freshwater, treated wastewater), period of the year (see annex 3). The price of water is set at 0.04 €/m^3 for freshwater and 0.02 €/m^3 for treated wastewater, according to official data and official invoices (GDA and farmers). The irrigation system used in all farms (F1, F2 and F3) is drip irrigation with an irrigation efficiency equal 85% (DGA).

The water availability scenario (TWW reuse)

In this scenario, we are considering an increase in water availability obtained from treated wastewater reuse, particularly in summer to simulate a continuous flow of water throughout all the irrigation period. Two simulations were defined: In the first simulation (annex 3: 1.1), all freshwater availability is replaced by treated wastewater in both periods (summer and winter); In the second simulation (annex 3: 1.2), farmers can mix the two types of water (freshwater and treated wastewater), which applies only to F1 and F2 because F3 already uses treated wastewater. In both cases (1.1 and 1.2), the assigned amount of treated wastewater varies according to periods and farms types (see annex 3). In this scenario, the price of water is set at 0.02 €/m^3 for treated wastewater and 0.04 €/m^3 for freshwater.

The technology scenario (Irrigation management)

In this scenario, a new irrigation technology (calibrated nozzles) is considered, assuming that irrigation efficiency is enhanced up to 95% and the cost of calibrated nozzles is the same as traditional nozzles. The rest of the parameters (water price, etc.) are the same as used in the baseline scenario.

The policy scenarios (Economic instruments for water management)

In this scenario, we consider that the price of freshwater is subsidized (annex 3: 3.1) and equal to the price of treated wastewater (0.02 €/m^3), and that the price of treated wastewater is no longer subsidized (annex 3: 3.2) and equal to the price of freshwater (0.04 €/m^3). Also, different economic instruments are included: Water pricing (annex 3: 3.3), simulated as a gradual increase of 0.02 €/m^3 in freshwater or treated wastewater price for twenty price levels, to analyze the capacity to adapt of the different representative farms; and Water quotas (annex 3: 3.4), simulated as a gradual decrease in freshwater or treated wastewater availability, to examine the hypothetical application of a more restrictive environmental policy in the region.

3.2. Water reuse and water & land management in agriculture under different scenarios: results and discussions

3.2.1. Egypt case study

3.2.1.1. The baseline (calibration) scenario

The simulation results for the baseline scenario show the same cropping pattern **of the actual situation, where the total area of 185 ha is divided as follows (Figure 27: Cropping pattern in the baseline scenario, Egypt**

):

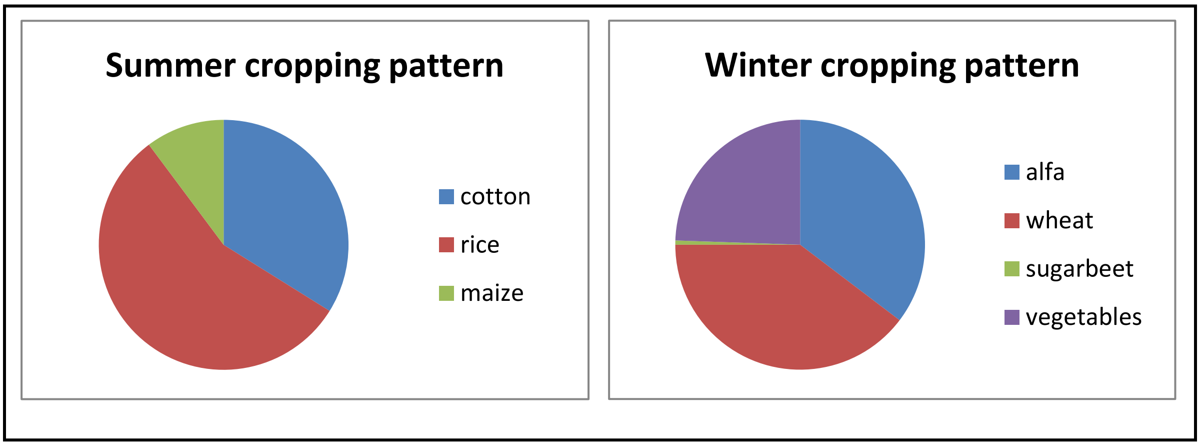


Figure 27: Cropping pattern in the baseline scenario, Egypt

The total and per hectare yearly water demand (corresponding to the gross irrigation requirements) predicted by the model in the three different portions of the canal according to the different cropping pattern and the irrigation requirements of the crops together as well as the amount of **drained_reused water** are given in Table 35 and Table 36, respectively. In the WWT_2016 model, the volume of drained water represents the amount of "additional water supply" that is needed and used by the farmers in order to cover the "deficit" between water supply and requirement.

Table 35: Water demand, Baseline scenario, Egypt

Water used (m^3)	
Total	4 226 196
Per ha	22 851
Head_ha	21 717
Middle_ha	22 529
Tail_ha	24 560

Table 36: Drained water, Baseline scenario, Egypt

Drained Water (m^3)	
Total	936 818
Per ha	5 063
Head_ha	2 406
Middle_ha	3 859
Tail_ha	9 460

The capacity of the system to satisfy the demand of water of the farmers under the current conditions can be estimated by calculating the **System performance index** – given by the ratio between the amount of water supplied and the gross irrigation requirements - that in the baseline is equal to:

Table 37: System performance index, Egypt

System performance index	
Total	0.78
Head	0.89
Middle	0.83
Tail	0.61

Finally, **farmer's income** is also estimated by the model and it is equal to an average amount of 3481 Euro/ ha/y.

3.2.1.2. The Technology scenario

With a cropping pattern similar to the baseline scenario's one, the introduction of the gated pipe on the surface irrigated with the traditional furrow system affects the **total and per hectare yearly water demand** (Table 38). By increasing the efficiency of the system, gated pipe contributes to reduce the gross irrigation requirements by 9,2%, 11,6% and 15,3 % for the head, middle and tail section, respectively.

Table 38: Water demand, Technology scenario, Egypt

Water used (m^3)	
Total	3 720 227
Per ha	20 116
Head_ha	19 706
Middle_ha	19 908
Tail_ha	20 810

Consequently, the **System performance index** - i.e. the ratio between supply and demand of water – increases (Table 39) and induces farmers to reduce the amount of **drained reused water** re-pumped into the systems (Table 40).

Table 39: System performance index, Technology scenario, Egypt

System performance index	
Total	0.88
Head	0.98
Middle	0.73
Tail	0.61

Table 40: Drained total water, Technology scenario, Egypt

Drained Water (m^3)	
Total	430 850
Per ha	4 892
Head_ha	5 859
Middle_ha	6 095
Tail_ha	2 641

The joint effects of energy cost saving due to the reduced drained water re-pumped and the cost of the new technology determines a very slight decrease in **farmer's income** from 3481 Euro/ha/year (baseline scenario) to 3 368 Euro/ha/year in the new scenario.

3.2.1.3. The Water Availability scenario

In combination with the efficiency gains achieved in the technology scenario, the reduction of water supplied to farmers assumed in the Water Availability scenario, affects, of course, both the **System performance index** (Table 41) and the amount of **drained reused water** re-pumped, see Table 42.

Table 41: System performance index, Water Availability scenario, Egypt

System performance index	
Total	0.80
Head	0.88
Middle	0.84
Tail	0.65

Table 42: Drained total water, Water Availability scenario, Egypt

Drained Water (m^3)	
Total	759 797
Per ha	4 108
Head_ha	2 326
Middle_ha	3 105
Tail_ha	7 220

In order to satisfy the irrigation requirement of the crops, farmers are obliged to push up the **amount of reused drainage water** by also increasing the energy bill. Further, given the uniform reduction of the water supply by 10% in the three sections of the mesqa, the effect on the amount of water drained are increasingly accentuated from the upstream to the downstream section given the increasing efficiency recovery.

As results of the new conditions, **farmers' income** decreases by about 4.2% on average compared to the baseline due to higher costs to sustain investments and operation & maintenance of the new technology of gated pipes and to the failure to reduce the re-use of drainage and therefore the energy costs.

3.2.1.4. The Policy scenarios

Given the negative effects on farmers' income, in order to induce farmers to adopt the gated pipe technology, government could totally or partially cover the addition cost for investment and/or for O&M.

If the total cost of investment and O&M are covered**, farmers' incomes** return substantially to the levels of the base scenario while all water related parameters – gross water requirements (Table 43) **System performance index** (Table 44), and **drained_reused** - take advantages from the introduction of the technologies.

Table 43: Water demand, Policy scenario, Egypt

Water used (m^3)	
Total	3 720 227
Per ha	20 116
Head_ha	19 706
Middle_ha	19 908
Tail_ha	20 810

Table 44: System performance index, Policy scenario, Egypt

System performance index	
Total	0.80
Head	0.88
Middle	0.84
Tail	0.65

An alternative policy that could be implemented to encourage the adoption of the innovation is to "act" on the energy price: given that the convenience of the new technology for the farmers substantially depends on the comparison between the cost of implementing and managing the technology, on the one hand, and the energy cost saving, on the other hand, increasing the energy price can have a positive impact on the adoption of the gated pipe technologies. In this case different levels of energy price have been changed in both in the baseline scenarios and in a policy scenario b), in order to identify the switch-point, i.e. the energy price that makes the gated pipe technologies convenient. The switch point is equal to 3 times the current price for energy.

3.2.1.5. Discussion

Results of the simulated scenarios provide with some useful elements to draft water resources management strategies in the area.

Given the availability of a technology able to improve the traditional irrigation widely used in Egypt into an innovative and more efficient system, the implementation of some economic tools is simulated in order to evaluate their effects in terms of reduction of drainage water and hence of water quality deterioration.

Obtained results demonstrate that the introduction of the gated pipe allows to achieve two relevant positive impacts: i) to reduce the drained water re-pumped into the system and, consequently, reduce the quality deterioration of the water available for irrigation practices (MADFORWATER, 2019b), and ii) to improve the equity of the system measured as the difference among the ratio between the water supply and the gross irrigation requirement of the cultivated crops in the different sections of the mesqa.

However, the adoption of the gated pipe technology could be not accepted by the farmers since, notwithstanding the energy cost saving due to the reduced amount of drained water re-pumped into the system, farmers' income decreases slightly, due to the investment and O&M costs of the gated pipe technology (Figure 28).

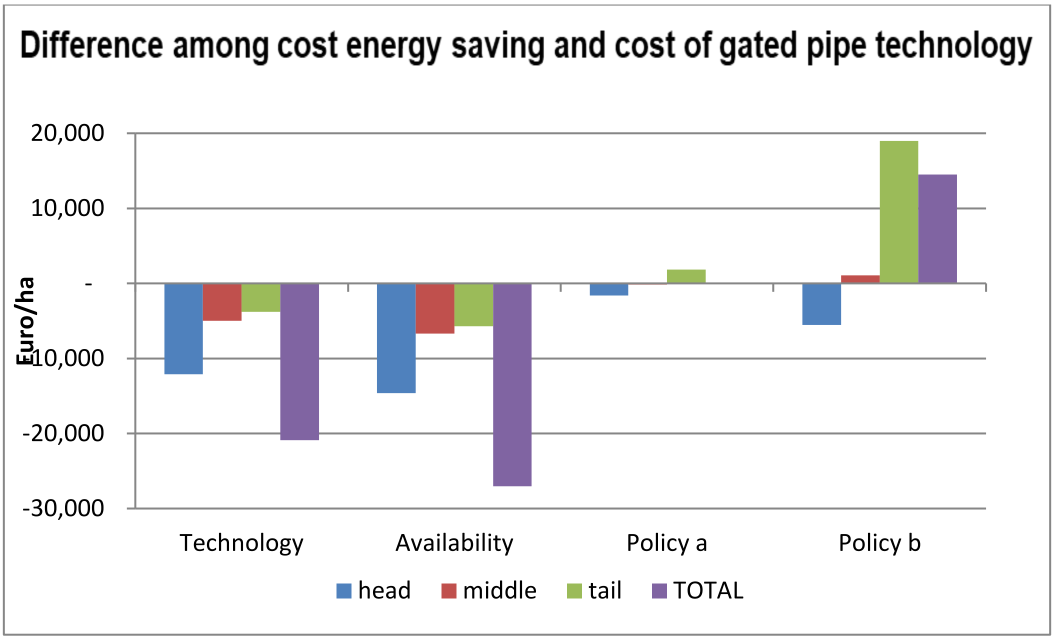


Figure 28: Difference among cost energy saving and cost of gated pipe technology, Egypt

As shown in Figure 28, only by fully covering the total cost of the investment and O&M, the energy savings in terms of costs exceed the cost of the gated pipe with a positive impact on farmers' income and a consequent favorable attitude of farmers towards the adoption of innovation.

Obtained results also show that the mere introduction of gated pipe is not able to contribute to reduce the weight of the agricultural sector on the country's total water consumption if the efficiency gains are not “transferred” into the water policy. The “transmission” of the efficiency gains into a new water policy is crucial to determine the effects of the measures simulated. Our results indicate that only the joint introduction of the innovation and of a new policy of water supply could achieve the objective to reduce the amount of water used by agriculture without affecting the level of satisfaction of the farmers. On the other side, the combined implementation of the gated pipe and of a new policy of water supply partially reduces the effects on the drained water.

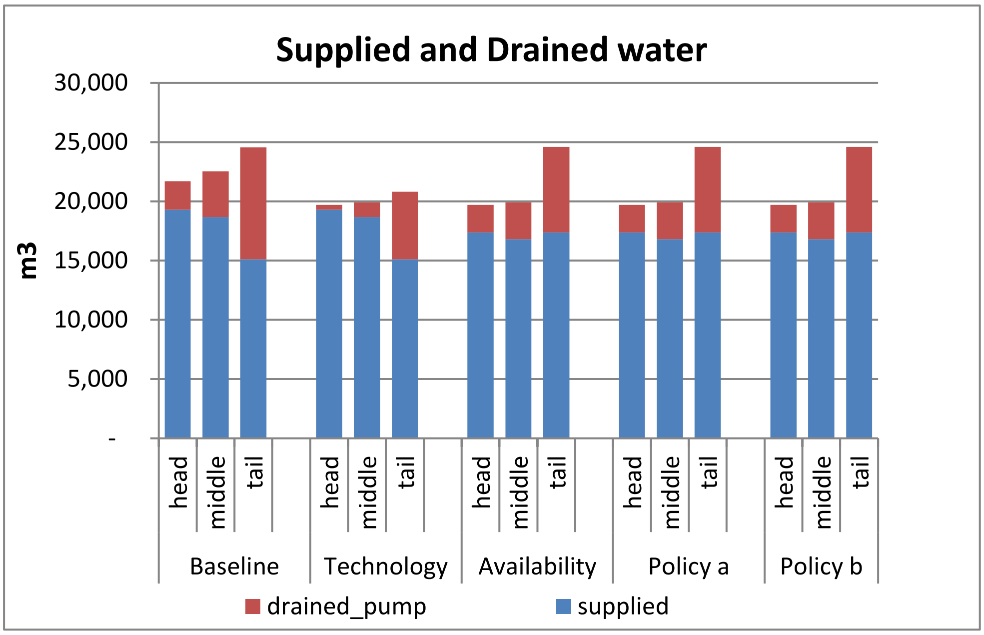


Figure 29: Supplied and drained water in the different scenarios and in the three sections along the mesqua, Egypt

From the simulated scenarios, it also emerges that the costs to achieve these important results can be distributed differently between farmers and the community. However, a partial coverage of the costs seems to be a condition for the adoption of the technology by farmers: with a coverage of 30% of the only O&M costs it is possible to preserve the starting income levels and obtain significant results in terms of reduction in water consumption and total drainage.

Furthermore, it could be useful to evaluate the possible effects on crop yields deriving from the use of variable percentages of reused water.

To conclude it is important to stress that, since different and conflicting objectives can be achieved, it is crucial to define the priorities among the different objectives – reduction of water demand, reduction of the reused drainage, economic performance of the farmers and their level of satisfaction – in order to design the most effective water policies in this area.

3.2.2. Morocco case study

3.2.2.1. The baseline (calibration) scenario

The simulation for the baseline scenario shows a cropping pattern similar to the actual situation to a level of 96.2 %, indicating that the model is well calibrated. The chosen citrus varieties are distributed as follows: Clementine 39% of the total area, Navel 15%, 28% is occupied by Maroc late, while Nour is planted on 15% and Nadorcott on 4% of the total land. All crops are irrigated with freshwater.

The total and the specific water quantities used in the baseline scenario are equal to 218 449 511 m3 and 6 764 m3/ha, respectively while the **total and specific fertilizers quantities** are presented in the following Table 45.

Table 45: Fertilizers used, Moroccan case study

Fertilizers used[3]	
Nitrogen (Kg)	18 930 949
Nitrogen (Kg/ha)	586.2
Phosphorus (kg)	2 319 828
Phosphorus (kg/ha)	71.8

For the baseline scenario**, the total cost of water and the average cost per hectare** amount to 32 767 427 Euro and 1 014 Euro/ha, respectively (Table 46).
Considering all costs and benefits, the total farmers' income is calculated. The total farmers' income and the **average income** per unit of area is obtained by dividing the total income by the cultivated land and are given in Table 47.

Table 46: Water cost, Moroccan case study

Water Cost (Euro)	
Total	32 767 427
Per ha	1 014

Table 47: Farmers' income, Morocco

Farmers' income (Euro/y)	
Total	274 001 580
Per ha	8 485

3.2.2.2. The Water Availability Scenario

Given the several assumptions that define this scenario (the current prices of wastewater - 0.23 Euro/m3 - and fresh water - 0.15 Euro/m3 -, the efficiency for the system equal to 0.85 for wastewater and 0.95 for freshwater, and the reductions in yield obtainable by irrigating with TWW), the results have shown that TWW reuse does not appear in the optimal solution as an irrigation water source.

Farmers' that maximize the expected income choose to continue to use the conventional resources notwithstanding the availability of an additional water source for irrigation.

The cultivated land is totally irrigated with fresh water and, consequently, the **amount of water used**, the **total and average water costs**, the **total and average fertilizers** amounts and the **famers' income** remain the same compared to the baseline scenario.

[3] Nitrogen is supplied to the plant in the form of Ammonitrate, which contains 33 % of N. Phosphorus is supplied in the form of MonoAmmonium Phosphate (MAP), containing 62 % of P_2O_5

3.2.2.3. The Policy scenarios

Given the non-appearance of TWW as a source for irrigation in the availability scenario, a water price policy scenario is simulated by decreasing the price that farmers have to pay to use the un-conventional resource. It is to be noted that different simulations have been carried out with gradually decreasing the cost of TWW from its actual level - 0.23 Euro/m3 - to 0.1 Euro/m3, the value that leads to the switch to TWW. Indeed, as shown in Fig. 29, farmers decide to substitute freshwater with TWW when the price that they have to pay is equal or lower than 0.1 Euro/m3. Below this threshold, about 40% of the total irrigated area results not be irrigated with TWW, according to the model.

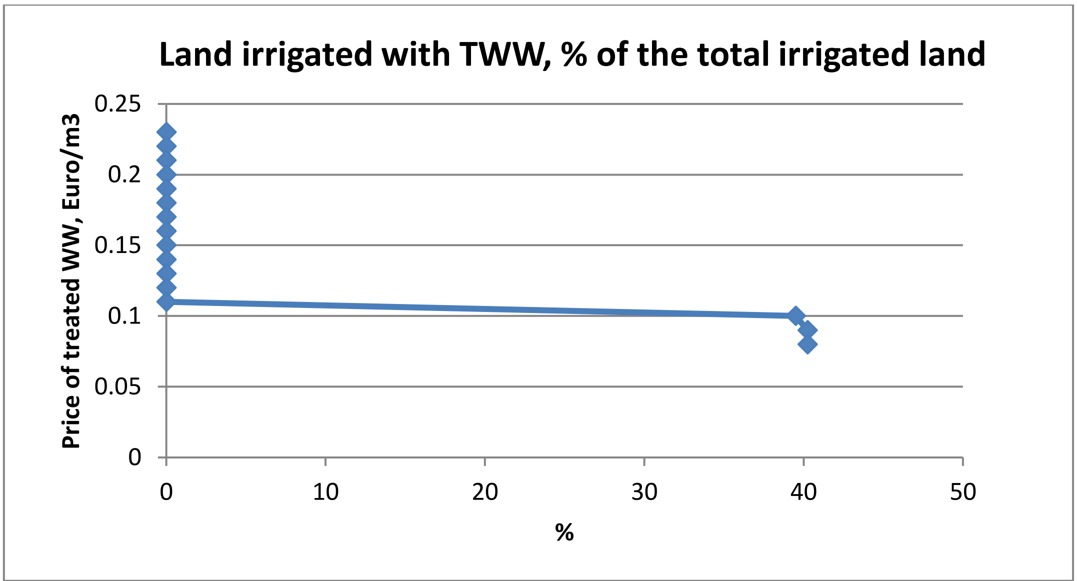


Figure 30: Land allocation for water source, Morocco

Assumed the lower efficiency level that the system reaches when TWW is used, in order to satisfy the net irrigation requirements of each variety, the average amount of TWW used is higher than the average amount of fresh water. For this reason, the variety that switched to TWW – Clementine – is that characterized by the lowest water requirement as well as the highest consumption of fertilisers, so that the switch to TWW can be offset by savings in fertilizers.

Since the land allocation according to the water source has changed, the **annual amount of water used** for each source will also change as shown in Table 48. The total freshwater required by the citrus sector decreases by 64% compared to the current level.

Table 48: Water used, Policy scenario, Morocco

Water used (m3)	
Freshwater (Total)	140 507 230
Freshwater (per ha)	7 193
TWW (Total)	86 850 330
TWW (per ha)	6 807

With a water price equal to 0.1 Euro for one cubic meter of TWW, **the total and average water costs** are equal to 29 761 118 Euros and 921 Euros/ha, with a 10% reduction in comparison with the baseline situation.

As for **fertilizer consumption**, by comparing the average amount of fertilizer used in the baseline scenario with the average amount used when part of the crops are irrigated with TWW, results show that TWW allows the saving of important amounts of fertilizers equal to 38.5% and 37.5% for nitrogen and phosphorus, respectively, which determines an additional economic saving for the farmer and a contribution to the environment. The combined effects on yields, on cost of water and on cost for fertilizers translates into a not significant variation of **total and average income per hectare,** equal to 274 662 274 Euro and 8 505 Euro/ha, respectively.

3.2.2.4. The Technology scenario

In this scenario, the new micro-sprinkler technology developed in the framework of MADFORWATER has been introduced into the model. This technology is assumed to retrieve the loss of application efficiency, due to its compatibility with low-quality water sources. Therefore, the application efficiency of the irrigation system is increased to 95%, coupled with an additional annualized cost for the implementation of this technology (350 Euro/ha).

Results show that TWW does not appear as an adequate source for irrigation in this scenario. The total land is irrigated with freshwater, identical to the baseline scenario. Similarly, **the total and average amounts of water used**, and the **fertilizers amounts** are the same as in the baseline scenario. The annual **average cost of water** as well as the **farmer's income** remain also the same compared to the baseline scenario.

An additional simulation was carried out, assuming that the full cost of the technology is covered by a subsidy granted to farmers. Also, in this case, the farmers decide not to use the TWW since, notwithstanding the full recovery of the efficiency's loss, the penalization of yields are not compensated by the cost saving of fertilizers.

3.2.2.5. Discussion

Results of the simulated scenarios provide some useful elements to draft water resources management strategies in the area.

Farmers' decision about the use of TWW only changes in the water price policy scenarios, when the price of TWW is subject to a certain level of subsidies. Compared with the baseline scenario, 40% of the total land switches to TWW as a source for irrigation. On the contrary, in the water availability and technology scenarios, the cultivated land is totally irrigated with fresh water. We can also deduce that the switch from fresh water to TWW happens to varieties with the least annual water requirements, which is due to the difference between fresh water and TWW in terms of application efficiency. Therefore, the least water demanding crops will be less affected by this loss.

The substitution of fresh water with TWW allows the conservation of an average amount of 2414 m3 of fresh water per hectare. This important amount has a great socio-economic value, since it can be used for other crucial activities, such as drinking water.

The simulations carried out also reveal that the reuse of TWW helps to save important amounts of fertilizing elements. This results in lower production costs for the farmer, thus confirming impressive results on cereals, forage and vegetable already documented in the literature (Hamdy and Choukr-Allah, 2003).

As for the average annual water costs, in the water availability and technology scenarios it is identical to the baseline scenario since the total land is irrigated with fresh water. In the policy scenario, where the price of TWW (0.1 Euro/m3) is lower than that of freshwater, the annual water cost has decreased compared to the baseline scenario. These results indicate that subsidies through the water pricing policy are needed to cover the difference in water consumption due to the loss of application efficiency and to the negative effects on crops' yields.

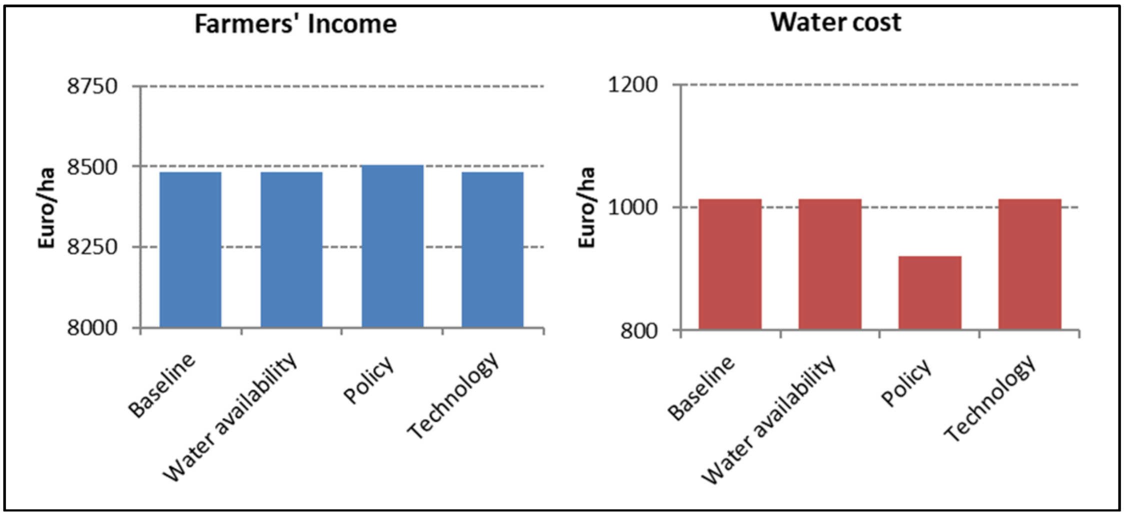


Figure 31: Water Cost and Farmers' Income for the different scenarios, Morocco

The comparison between the amount of subsidies per unit area and of average income per unit area shows that, in order to achieve a gain of 20 Euro/ha in the farmers' income, 350 Euro/ha of public subsidies are needed. This analysis demonstrates that subsidizing the price of TWW to a level where its cost is lower than fresh water is not justified from a pure economic point of view. However, a more holistic evaluation should also take into account the economic value of the environmental benefits that TWW reuse can generate.

In the case of the technology scenario, the micro-sprinkler technology adapted to low-quality water was introduced and simulations were carried out assuming that the additional cost for the implementation of this technology is subsidized, keeping the cost of TWW at its actual level. As shown in the results of the Technology scenario, TWW is not suggested as an optimal solution for irrigation, even when the technology cost is totally subsidized. This signifies that the gain in efficiency allowed by the technology does not help to account for the difference in water cost.

Combining the obtained results, it can be concluded that the TWW reuse promotion require to overcome the lack of social acceptance due to inadequate information on benefits (Massoud et al., 2019), incomplete economic analysis of TWW reuse options, misalignment between water prices and water scarcity and lack of economic incentives for re-use (Frascari et al., 2018).

The results obtained show that the farmers' advantage of saving fertilizer costs could be significant, but farmers should be able to assess these potential savings and to adopt optimal nutrient management strategies. However, with the current price level for the two water sources (0.15 Euro/m3 and 0.23 Euro/m3 for fresh and TWW respectively), this positive effect is not sufficient to make TWW reuse an attractive option, thus confirming the low demand for treated waste water reported in the literature (Jeuland, 2015).

The economics of reuse will not be favorable as long as the price of conventional water remains so far below the actual cost of water if, as in this case study, users do not suffer acute shortage of water and have a choice between conventional water and TWW.

The increase in TWW supply must be associated with a good water resource design policy that fills the widespread lack of effective price signals (El Yacoubi and Belghiti, 2002) and restructures the reuse funding.

In fact, with subsidies equal to 0.13 Euro/m3 for the TWW used by farmers - equal to the difference between the actual cost and the price paid by farmers -, about 40% of the cultivated land is irrigated with TWW and 2414 m3/ha of fresh water are saved.

It was also found that decreases in wastewater treatment costs – which will vary depending on the extent to which wastewater processing is developed – could contribute to its reuse. In addition, the evaluation of saved fresh water could help to raise public awareness on the effectiveness and opportunities for reuse, emphasizing the "social benefit" generated by this reuse.

It is also to be mentioned that conditions and assumptions on the basis of which the above results have been obtained could change in the future: increasing water scarcity for the agricultural sector could eliminate the choice between the sources that is still preserved in the Moroccan irrigation sector, and the total or partial substitution of fresh water with different sources of non-uniform quality irrigation water will become one of the main future research lines to be explored (Reca et al, 2018).

3.2.3. Tunisia case study

In this section, we are presenting the results of the Tunisia case study at two different levels of aggregation, at the level of the farm and at basin level. Farm level results have been obtained by applying the DST model (see section 3.1.3) specified for each of the three selected representative farms and are largely based on the extended fieldwork that has been conducted in the area of study along three different periods (see section 3.1.3.2). These results capture the way the farmers develop their cropping and input use strategies when they are confronted to different types of technologies as well as socio-economic scenarios. The aggregated results have been developed taking into account a detailed structural analysis based on the surface weight that each type of farm has on the overall area of the basin. To conduct the aggregation, the analysis has also been based on the fieldwork carried out at the level of the 18 irrigation districts (GDA), that cover 95% of total irrigated area in the basin, each of which includes different types of farms and different number of farms ranging from a minimum of 86 farms (GDA Somaa) to a maximum of 456 farms (GDA Korba). The results at basin level illustrate the impact of the same type of simulated scenarios in the whole Cap-Bon basin. Both levels of aggregation have proven to be of great importance for analyzing any type of policy intervention based on the application of wastewater management technologies and water reuse and land management technologies as well as economic instruments. The following sections are organized according to the simulated scenarios.

3.2.3.1. The baseline (calibration) scenario

Cropping patterns of the baseline scenario simulation and the comparison with each representative farm can be seen below in Figure 32 . These results are those of the calibrated model.

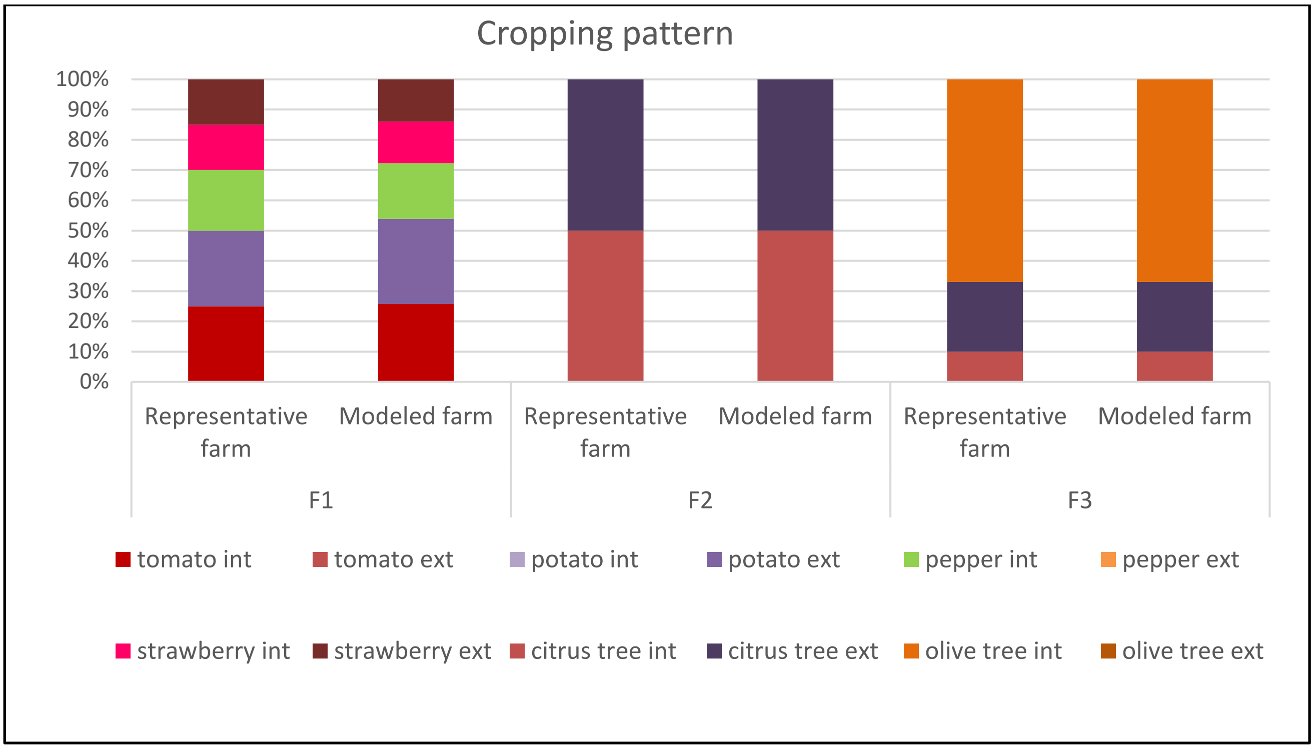


Figure 32: Calibration results

Regarding farm F1, the level of correspondence between representative farm and modeled farm is 98% for tomato intensive (0.750 ha in F1 representative farm, and 0.735 ha in F1 modeled farm), 94% for potato extensive (0.750 ha in F1 representative farm, and 0.705 ha in F1 modeled farm), 88% for pepper intensive (0.600 ha in F1 representative farm, and 0.528 ha in F1 modeled farm), 87% for strawberry intensive (0.450 ha in F1 representative farm and 0.392 ha in F1 modeled farm) and 89% for strawberry extensive (0.450 ha in F1 representative farm and 0.400 ha in F1 modeled farm) . Regarding farms F2 and F3, the level of correspondence between representative farms and modeled farms is 100%.

In the baseline scenario, the farm F1 (vegetables) presents the highest income value with 4226 €/ha, resulted from the cultivation of productive and profitable crops such as strawberry and tomato. The amount of irrigation water per hectare applied for F1 is 4179 m^3/ha, which results in a high economic productivity of irrigation water of about 1.01 €/m^3. All the available water for farm F1 is consumed, which results in a water marginal value equal to 0.27 €/m^3. Regarding F2, the farm income value is equal to 2808 €/ha and the water consumption per hectare is equal to 4500 m^3/ha, which results in a low irrigation water productivity (0.62 €/m^3). Water marginal value is equal to 0.28 €/m^3, it reflects that famers used all the available water. Regarding F3, the farm income value is equal to 2723 €/ha and the water consumption per hectare is equal to 2000 m^3/ha that results an irrigation water productivity equal to 1.36 €/m^3. F3 presents the highest water marginal value with 0.47 €/m^3, reflects that F3 is facing the highest water scarcity, comparing with F1 and F2. These results are in line with the current situation observed during the fieldworks.

With respect to the aggregated level, the results for the baseline scenario are following: the income is equal to 3443.92 (€/ha) and the water consumption is equal to 3595.87 m3/ha of freshwater and 336.42 m3/ha of treated wastewater. The crop distribution is presented in the following table 49 that shows relevant indicators at farm level as well as aggregated level in the baseline scenario.

Table 49: Indicators for the baseline results

Indicators	Farm types			Aggregate results
	F1	F2	F3	
Farm income (€/ha)	4226	2808	2723	3443.92
Water availability (m^3/ha)	4179 (FW)	4500 (FW)	2000 (TWW)	3595.87 (FW) 336.42 (TWW)
Water consumption (m^3/ha)	4179 (FW)	4500 (FW)	2000 (TWW)	3595.87 (FW) 336.42 (TWW)
Water Price (€/m^3)	0.04 (FW)	0.04 (FW)	0.02 (TWW)	0.04 (FW) 0.02 (TWW)
Water marginal value (€/m^3)	0.27	0.28	0.47	0.23 (FW) 0.08 (TWW)
Irrigation efficiency	0.85	0.85	0.85	0.85
Crop distribution (%)	Pep.int (17.50%) Tom.int (24.40%) Pot.ext(26.70%) Str.int (13.03%) Stra.ext (13.30%) Fallow (5.07%)	Cit.int (43%) Cit.ext (43%) Fallow(14%)	Oli.int (67%) Cit.int (10%) Cit.ext (23%) Fallow (0%)	Pep.int (8.02%) Tom.int (11,19%) Pot.int (0%) Pot.ext (12.24%) Str.int (5.97%) Str.ext (6.10%) Cit.int (17.73%) Cit.ext (19.92%) Oli.int (11.27%) Fallow (7.70%)

The baseline scenario will be compared with different scenarios, characterized by different inputs in terms of water resources availability, irrigation technologies and water policies.

3.2.3.2. The water availability scenario (TWW use)

- Increase in water availability considering water supply from WW reuse

Assuming that all freshwater availability is replaced by treated wastewater throughout all the irrigation period (table 50), results show an increasing by 32.2%, 11.28% and 15.31% in famers' income for F1, F2 and F3 respectively. This increase in farmers' income is explained by the new crop distribution, by obtaining more water, farmers prefer to cultivate profitable crops. Regarding farm F1, the strawberry area increased from 26.33% in the baseline scenario to 40.16% in the water availability scenario, as strawberry is a profitable crop. In the other side, potato area reduced from 26.70% in the baseline scenario to 11.26% in the water availability scenario. Regarding F1 and F2 (permanent crops), farmers are moving towards extensive agriculture, in comparison to the baseline scenario.

With respect to the aggregated level, the farm income increases by 23.6 % in comparison with the baseline scenario. The treated wastewater consumption increased to quantity of 4932.28 m3/ha.

Table 50: Results for the increase in water availability scenario considering water supply from WW reuse

Indicators	Farm types			Aggregate results
	F1	F2	F3	
Farm income (€/ha)	5588	3125	3140	4256.92
Water availability (m^3/ha)	5179 (TWW)	5500(TWW)	3000(TWW)	0 (FW) 4932.28 (TWW)
Water consumption (m^3/ha)	5179	5500	3000	0 (FW) 4932.28 (TWW)
Water Price (€/m^3)	0.02	0.02	0.02	0.02
Water marginal value (€/m^3)	0.35	0.15	0.35	0.22
Irrigation efficiency	0.85	0.85	0.85	0.85
Crop distribution (%)	Pep.int (26.98%) Tom.Ixt (11.65%) Pot.int (11.26%) Str.int (13.80%) Str.ext (26.86%) Fallow (9.45%)	Cit.int (68.36%) Cit.ext (31.63%) Fallow (0%)	Oli.int (67%) Cit.int (26.89%) Cit.ext (6.10%) Fallow (0%)	Pep.int (12.37%) Tom.int (5.34%) Pot.int (5.16%) Pot.ext (0%) Str.int (6.33%) Str.ext (12.32%) Cit.int (30.04%) Cit.ext (12.83%) Oli.int (11.27%) Fallow (4.34%)

- Mix the two types of water TWW + FW

In this scenario, by obtaining another water source (Treated wastewater), farmers' income increased by 55.4% and 13.7% for F1 and F2 respectively, in comparison with the baseline scenario. Regarding the crop distribution, farmers cultivate more productive and profitable crops such as strawberry and tomato (farm F1) and intensive crops such as intensive citrus (farm F2).

At the aggregated level, the farm income increased by 35% compared with the baseline scenario. In addition, the water consumption increased in term of treated wastewater. In this case, farmers cultivate more strawberry and citrus.

This scenario is the most realistic scenario, so the next scenarios results will be compared with this scenario (only for F1 and F2. The results of F3 will be compared with the baseline scenario, since F3 is already use treated wastewater).

Table 51: Results for the water availability scenario considering the two water types (TWW and FW)

Indicators	Farm types			Aggregate results
	F1	F2	F3*	
Farm income (€/ha)	6565	3192	2723	4659.79
Water availability (m^3/ha)	4179 (FW) 1000(TWW)	4500 (FW) 1000 (TWW)	2000 (TWW)	3595.87 (FW) 1168.21 (TWW)
Water consumption (m^3/ha)	3964 (FW) 1000 (TWW)	4500 (FW) 1000 (TWW)	2000 (TWW)	3595.87 (FW) 1168.21 (TWW)
Water Price (€/m^3)	0.04 (FW) 0.02 (TWW)	0.04 (FW) 0.02 (TWW)	0.02 (TWW)	0.04 (FW) 0.02 (TWW)
Water marginal value (€/m^3)	0 (FW) 0.63 (TWW)	0.22 (FW) 0.25 (TWW)	0.47	0.06 (FW) 0.19 (TWW)
Irrigation efficiency	0.85	0.85	0.85	0.85
Crop distribution (%)	Pep.int (13.17%) Tom.int (30.94%) Pot.ext (8.96%) Str.int (19.74%) Str.ext (27.17%) Fallow (0%)	Cit.int (62.16%) Cit.ext (37.84%) Fallow (0%)	Oli.int (67%) Cit.int (10%) Cit.ext (23%) Fallow (0%)	Pep.int (6.04%) Tom.int (14.19%) Pot.int (0%) Pot.ext (4.11%) Str.int (9.05%) Str.ext (12.46%) Cit.int (24.88%) Cit.ext (17.99%) Oli.int (11.27%) Fallow (0%)

*F3: same results as the baseline scenario.

3.2.3.3. The technology scenarios (Irrigation management)

- Irrigation efficiency considering innovative technologies: Calibrated nozzles

In combination with the increase in water availability considering water supply from WW reuse and mixing the two water types (freshwater and treated wastewater), assuming that irrigation efficiency is enhanced up to 95% and the cost of calibrated nozzles is the same as traditional nozzles, farmers' income increased by 5.7%, 2.3% and 19.7% for F1, F2 and F3 respectively. Profitable crop area (strawberry and tomato) increased and farmers are moving towards intensive agriculture.

The three farm types are not satisfied with the amount of water available to fulfill the crop water requirements; it is explained by the water marginal value greater than zero.

With respect to the aggregated level, the farm income increased by 6.22% and the wastewater consumption increased from 1168.21 m3/ha to 1336.42 m3/ha and the freshwater consumption remained the same as the reference scenario. Table 52 shows the results for the technology scenario both at farm level and at aggregated level.

Table 52: Results for the technology scenario

Indicators	Farm types			Aggregate results
	F1	F2	F3	
Farm income (€/ha)	6940	3267	3259	4949.90
Water availability (m^3/ha)	4179 (FW) 1000 (TWW)	4500 (FW) 1000 (TWW)	3000 (TWW)	3595.87 (FW) 1336.42 (TWW)
Water consumption (m^3/ha)	3495 (FW) 1000 (TWW)	4500 (FW) 1000 (TWW)	3000 (TWW)	3595.87 (FW) 1336.42 (TWW)
Water Price (€/m^3)	0.04 (FW) 0.02 (TWW)	0.04 (FW) 0.02 (TWW)	0.02 (TWW)	0.04 (FW) 0.02 (TWW)
Water marginal value (€/m^3)	0 (FW) 0.67 (TWW)	0.023 (FW) 0.10 (TWW)	0.35	0.06 (FW) 0.16 (TWW)
Irrigation efficiency	0.95	0.95	0.95	0.95
Crop distribution (%)	Pep.int (11.17%) Tom.int (31.67%) Pot.ext (7.10%) Str.int (21.04%) Str.ext (29.01%) Fallow (0%)	Cit.int (70.72%) Cit.ext (29.27%) Fallow (0%)	Oli.int (67%) Cit.int (31.44%) Cit.ext (1.59%) Fallow (0%)	Pep.int (5.12%) Tom.int (14.52%) Pot.int (0%) Pot.ext (3.26%) Str.int (9.65%) Str.ext (13.30%) Cit.int (31.68%) Cit.ext (11.19%) Oli.int (11.27%) Fallow (0%)

3.2.3.4. The policy scenario (Economic instrument for water management)

- Subsidizing Fresh Water (FW) (not applicable for F3)

Assuming that the price of freshwater is subsidized and is equal to the price of treated wastewater (0.02 €/m^3), the farmers' income as well as the crop distribution remain the same compared to the reference scenario (1.2) both at farm level and aggregated level. As a result, this scenario is not important.

Table 53: Results for subsidizing fresh water

Indicators	Farm types			Aggregate results
	F1	F2	F3*	
Farm income (€/ha)	6639	3193	2723	4694.09
Water availability (m^3/ha)	4179 (FW) 1000(TWW)	4500 (FW) 1000 (TWW)	2000 (TWW)	3595.87 (FW) 1168.21 (TWW)
Water consumption (m^3/ha)	3996 (FW) 1000 (TWW)	4500 (FW) 1000 (TWW)	2000 (TWW)	3595.87 (FW) 1168.21 (TWW)
Water Price (€/m^3)	0.02 (FW) 0.02 (TWW)	0.02 (FW) 0.02 (TWW)	0.02 (TWW)	0.02 (FW) 0.02 (TWW)

Water marginal value (€/m³)	0 (FW) 0.62 (TWW)	0.22 (FW) 0.25 (TWW)	0.47	0.06 (FW) 0.16 (TWW)
Irrigation efficiency	0.85	0.85	0.85	0.85
Crop distribution (%)	Pep.int (13.81%) Tom.int (31.07%) Pot.ext (8.31%) Str.int (19.70%) Str.ext (27.09%) Fallow (0%)	Cit.int (62.17%) Cit.ext (37.83%) Fallow (0%)	Oli.int (67%) Cit.int (10%) Cit.ext (23%) Fallow (0%)	Pep.int (6.33%) Tom.int (14.25%) Pot.int (0%) Pot.ext (4.81%) Str.int (9.03%) Str.ext (12.42%) Cit.int (24.88%) Cit.ext (17.99%) Oli.int (11.27%) Fallow (0%)

*F3: same results as the baseline

- Treated Waste Water (TWW) is not subsidized (same Price as FW)

Considering that the price of treated wastewater is no longer subsidized and is equal to the price of freshwater (0.04 €/m³), farmers' income reduced by 1.9%, 3.5% and 2% for F1, F2 and F3 respectively.

At the aggregated level, farm income reduces by 2.3%. Table 54 depicts the results for the scenario that treated wastewater is not subsidized at farm level and at basin level.

With the objective of promoting incentives to accept treated wastewater, it is necessary to applicate subsidies for this water type, as surveyed farmers are reluctant to accept treated water.

Table 54: Results for the scenario that TWW is not subsidized

Indicators	Farm types			Aggregate results
	F1	F2	F3	
Farm income (€/ha)	5484	3015	3080	4158.09
Water availability (m³/ha)	5179 (TWW)	5500 (TWW)	3000 (TWW)	4932.28 (TWW)
Water consumption (m³/ha)	5179 (TWW)	5500 (TWW)	3000 (TWW)	4932.28 (TWW)
Water Price (€/m³)	0.04 (TWW)	0.04 (TWW)	0.04 (TWW)	0.04 (TWW)
Water marginal value (€/m³)	0.33 (TWW)	0.13 (TWW)	0.32 (TWW)	0.21 (TWW)
Irrigation efficiency	0.85	0.85	0.85	0.85
Crop distribution (%)	Pep.int (26.98%) Tom.int(11.65%) Pot.int (11.26%) Str.int (13.80%) Str.ext (26.86%) Fallow (9.45%)	Cit.int (68.36%) Cit.ext (31.63%) Fallow (0%)	Oli.int (67%) Cit.int (26.89%) Cit.ext (6.10%) Fallow (0%)	Pep.int (12.37%) Tom.int (5.34%) Pot.int (5.16%) Pot.ext (0%) Str.int (6.33%) Str.ext (12.32%) Cit.int (30.04%) Cit.ext (12.83%) Oli.int (11.27%) Fallow (4.34%)

- Water quotas

By simulating different levels of water availability (X axis) in freshwater (F1 and F2) and treated wastewater (F3) for the different farm types, the capacity that farms have to adapt to different levels of water scarcity can be analyzed by looking at the water shadow prices (Y axis). The water shadow price is the water marginal value which represent the maximum price that a farmer would be willing to pay for one extra cubic meter of water (Wang et al., 1996). It has been utilized extensively for evaluating the impact of water policies in water scarcity situations and discussed amply in the literature (Johansson et al., 2002, Turner et al., 2004, Hanemann 2006; Varela-Ortega et al. 2011). The value of water for the farmers is not constant and it tends to increase as less water is supplied to them. In response, farmers adjust to changing water availability by varying their cropping patters and farming technologies. Figure 33 depicts the shadow prices of water for different levels of water availability obtained in the model simulations for the different farm types (F1, F2 and F3). Results indicate that farm types have distinctive adaptive response to water availability. As we can see in the following figure, farm F2 and F3 (with permanent crops) cannot change their cropping patters when less water is available and therefore farmers are willing to pay less for an extra unit of water (a maximum of 1.2 €/m3, in F2 and 2 €/m3 in F3) with respect to the horticulture annual crops grown in F1 (a maximum of 3.3 €/m3). In fact, F1 can change its annual cropping pattern by growing less water demanding crops but, largely, this type of horticulture farms are very water demanding and therefore its adaptive capacity to water stress conditions results in a willingness to pay larger sums for extra units of water. In sum, in spite of being less flexible to changing crops annually, the citrus and olive farms F2 and F3 respectively are more adapted to water stress conditions than the vegetable farm F1. Looking at the curves' intersections with the X-axis it can be observed that F1 can satisfy its water requirements with 4800 m3/ha without willing to pay for extra units of water, equivalently F2 can operate with 5900 m3/ha. Comparing with F1 and F2, F3 requires less water volume (3400 m3/ha) to meet its crop water needs. This is can be explained by the fact that F3 cultivates olive trees that can be satisfied with less water volume. In contrast, F1 and F2 cultivate, respectively, vegetables (such as tomato and strawberry) and citrus that require a large water volume.

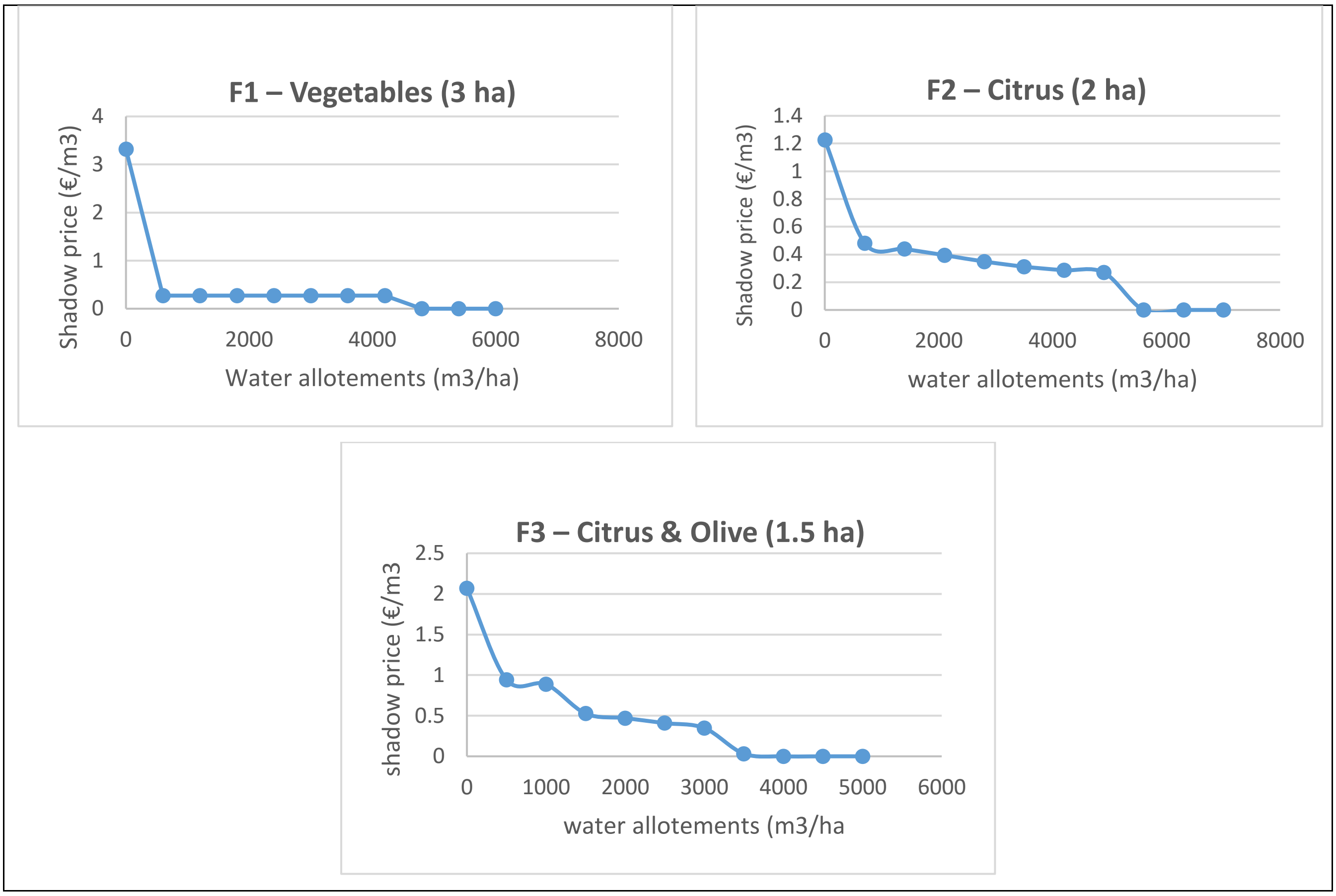


Figure 33: Water shadow prices in different farm types for different levels of water availability

- Water pricing

By simulating different levels of water price (Y axis) for the different farm types, we can analyze the capacity to adapt of the different representative farms in terms of water consumption (X axis). Figure 34 depicts the results of the application of different levels of water prices in the different farm types. Results indicate that the water demand responses to water prices are different across farm types due their different structural and technical characteristics (farm size and crop distribution). Farm F1 shows a low water demand elasticity between water prices ranging between 0.25 and 0.40 €/m3. This can be explained by the fact that in F1 (annual horticulture crops) farmers can change their crop distribution from intensive to extensive crops and by growing other types of crops that require less water. On the other hand, the permanent fruit-tree farms F2 and F3 have a higher water demand elasticity and respond to increasing water prices by reducing their water consumption in the farms.

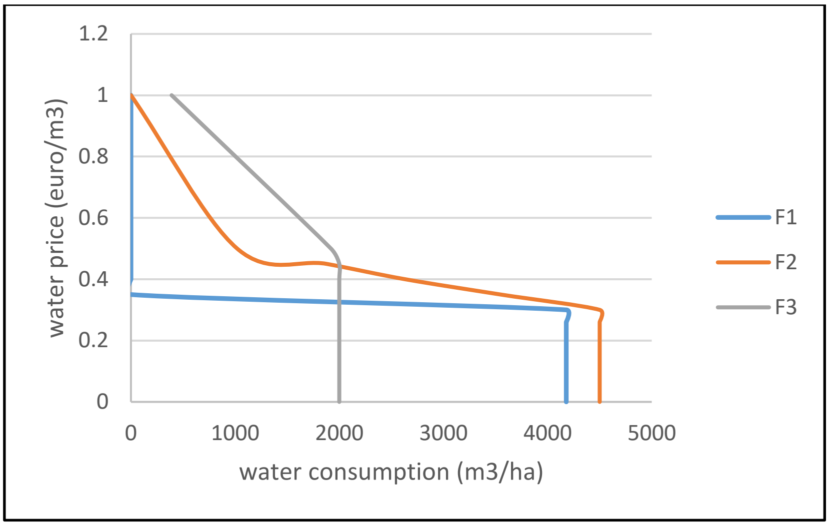


Figure 34: Water demand curves under uniform volumetric water prices

3.2.3.5. Discussion

In this section, the results of the scenarios simulation at farm level are aggregated at basin scale (Cap-Bon basin). Relevant indicators such as farm income, crop distribution and water consumption will be compared across different scenarios. Figure 35 shows the basin scale results on farm income under different scenarios. Results show that farm income has increased in all scenarios compared to the baseline scenario, explained by the fact that, with an additional quantity of water, farmers cultivate more profitable crops as we can see in figure 35, that shows that farmers cultivate more strawberry, citrus and tomato in comparison with the baseline scenario. These results are in line with the fieldwork results.

Scenario 2.1 that combines the water availability scenario and the technology scenario is suggested as the optimal scenario with an income gain of 1506 €/ha in comparison with the baseline scenario. Comparing scenario 3.2 (TWW is not subsidizes) with scenario 1.1, farm income decreases by 99 €/ha.

Based on these scenario simulation results, it can be underlined that the implementation of the MADFORWATER technologies has a positive effect on farm income.

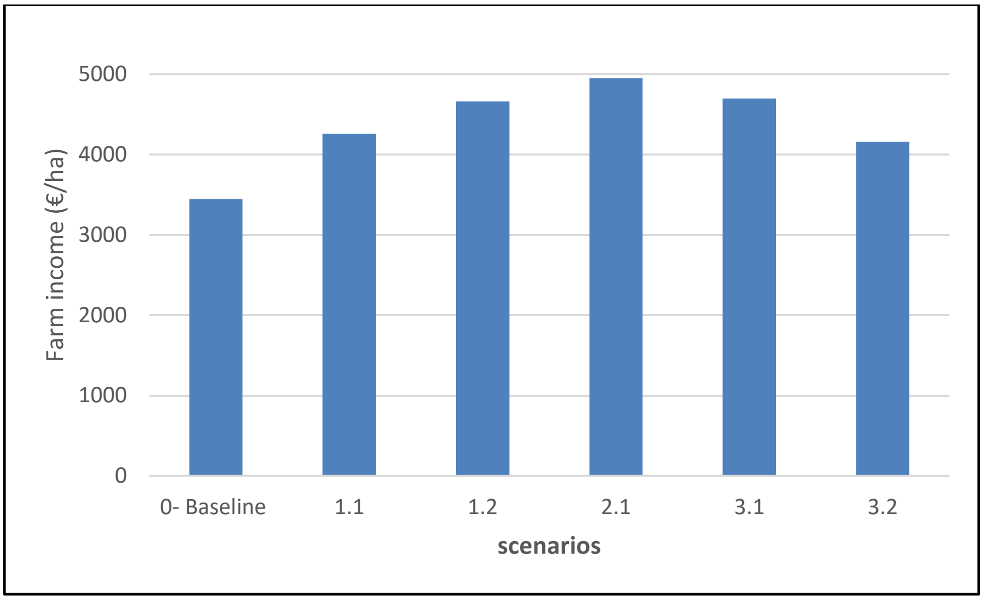


Figure 35: Aggregated results on farm income under different scenarios

Note:

1.1: The water availability scenario (TWW use): Increase in water availability considering water supply from WW reuse

1.2: The water availability scenario (TWW use): Mix the two types of water TWW + FW

2.1: The technology scenario (Irrigation management): Irrigation efficiency considering innovative technologies (Calibrated nozzles).

3.1: The policy scenario (Economic instruments for water management): Subsidizing FW

3.2: The policy scenario (Economic instruments for water management): TWW is not subsidized (same Price as FW)

Figure 36 depicts the basin-scale results of the farmers' cropping strategies under different scenarios. Aggregated results at basin-scale show rather similar results as compared to the farm-based results across scenarios. In comparison with the baseline scenario, we can see an increase in in the area dedicated to more profitable crops (Strawberry, tomato and citrus), and, in turn, a decrease in the area cultivated with less profitable crops such as potato. This increase in profitable crops can be explained by several factors. The most important factor is the additional amount of water that permit to cultivate the more water-demanding profitable crops. In fact, the Cap-Bon region is known for being a large producer of profitable crops such as citrus, strawberry and tomato that represent the highest proportion in the region in terms of area and production. In particular, Cap-Bon is considered an important producer of citrus accounting for 85% of the overall national production in 2016 (CRDA, 2016). In addition, the Cap-Bon region concentrated 63% of the national production of tomato in 2016, due to the growth of the number of industrial enterprises for the transformation of agricultural products such as tomato. According to the results of the scenarios simulations and in line with the fieldwork results, the implementation of MADFORWATER technologies as well as economic instruments is likely to promote the increase in the area of these productive and profitable crops.

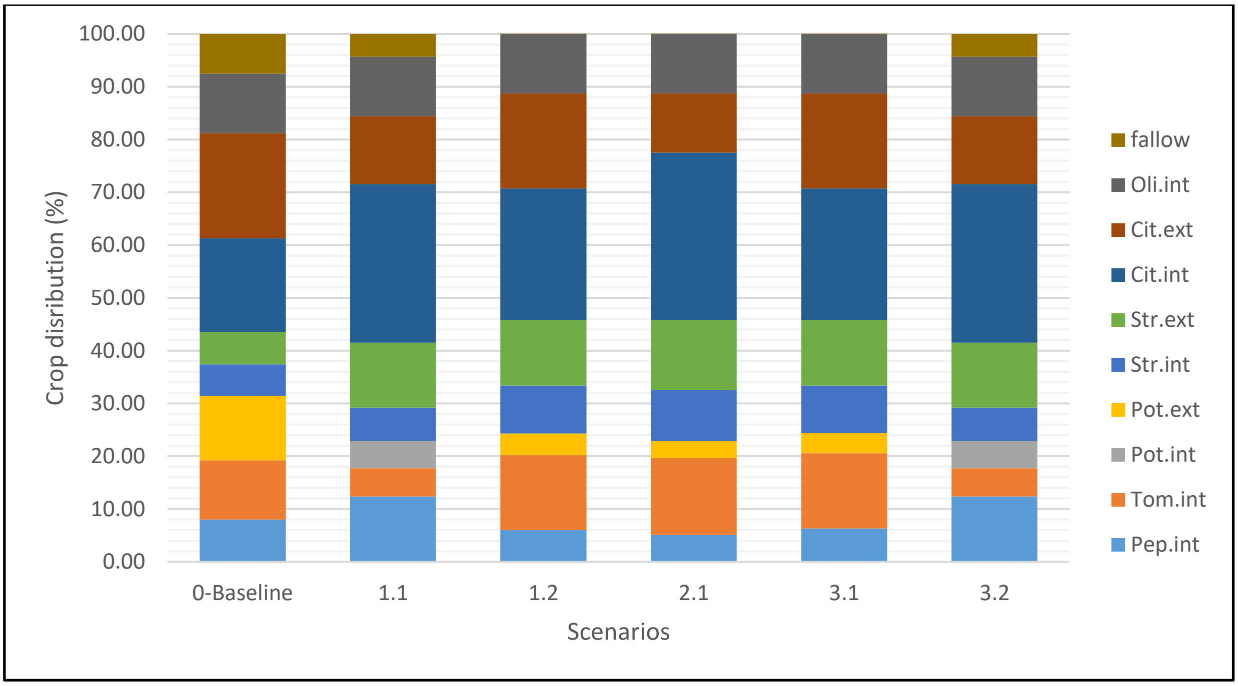


Figure 36: Aggregated results on farmers' cropping strategies under different scenarios

Note:

1.1: The water availability scenario (TWW use): Increase in water availability considering water supply from WW reuse

1.2: The water availability scenario (TWW use): Mix the two types of water TWW + FW

2.1: The technology scenario (Irrigation management): Irrigation efficiency considering innovative technologies (Calibrated nozzles).

3.1: The policy scenario (Economic instruments for water management): Subsidizing FW

3.2: The policy scenario (Economic instruments for water management): TWW is not subsidized (same Price as FW)

Figure 37shows the aggregated results on water consumption under different scenarios. Regarding treated wastewater, results indicate that crops consume all the available water and an additional volume in comparison with the baseline. However, it must be taken into account that according to the fieldwork interviews farmers are reluctant to accept this type of water and therefore the degree acceptability for the adoption of this type of technologies will need to be further considered. In fact, the reluctancy to accept reused wastewater for agricultural production was identified during the fieldwork series as one of the main barriers for using TWW mainly due to its appearance (color and smell). Accordingly, it will be necessary to develop ad-hoc incentives to promote the acceptance and adaptation of wastewater reuse in agriculture.

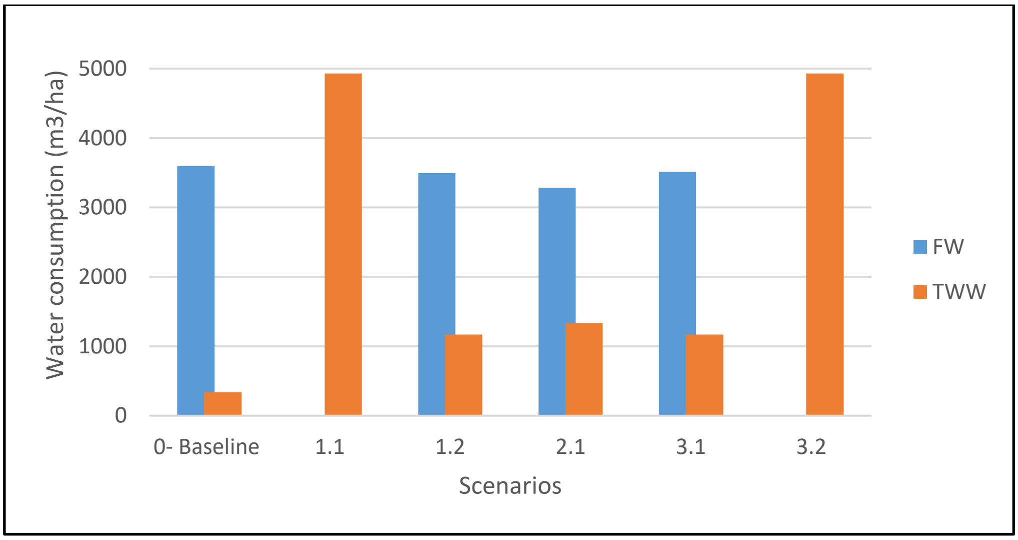


Figure 37: Aggregated results on water consumption under different scenarios

Note:

1.1: The water availability scenario (TWW use): Increase in water availability considering water supply from WW reuse

1.2: The water availability scenario (TWW use): Mix the two types of water TWW + FW

2.1: The technology scenario (Irrigation management): Irrigation efficiency considering innovative technologies (Calibrated nozzles).

3.1: The policy scenario (Economic instruments for water management): Subsidizing FW

3.2: The policy scenario (Economic instruments for water management): TWW is not subsidized (same Price as FW)

4. Concluding remarks

a) Wastewater management strategies

- For all the case studies, adapted treatment trains that could treat wastewater to the desired quality at reasonable costs were identified and are presented in this deliverable. The results show that technological options are available for water reuse but the concept is not widely implemented in Egypt, Morocco and Tunisia. The results depicted in this deliverable identify key barriers and drivers for the implementation of water reclamation for irrigation. In particular, the countries considered show different characteristics regarding efficient water management, water pricing, subsidies and wastewater tariffs, implementation of monitoring and reporting systems or legal aspects related to the use of reclaimed water for food crop irrigation. However, further exploration of case studies on high potential water reuse and financially affordable wastewater reclamation is required.

- Based on those case studies, we established exemplary basin-scale and national wastewater management strategies including economic instruments for Egypt, Morocco and Tunisia. We built the exemplary strategies upon the top-ranking options from the DST and from the MADFORWATER project pilot schemes. These options and corresponding technologies are complemented by the results of the multi-criteria decision analysis that identifies barriers, drivers and additional measures recommended to foster the implementation of sound solutions for water reuse in the region.

- The results of the analysis that identifies barriers, drivers and additional measures recommended to foster the implementation shows two different main additional measures that base on specific barriers: price-based instruments and non-economic instruments. These include increase enforcement and capacity building in general and increase of number of treatment technology and MADFORWATER technologies. The underlying barriers identified are: cheap available fresh water, lack of awareness and knowledge, legislation, and enforcement on wastewater reuse and further treatment facilities are required.
- The assessment indicated a high potential for water reuse in Egypt, Morocco, and Tunisia. In particular, Tunisia resulted with high water reuse level, followed by Egypt and Morocco. It showed that the policy context and social acceptance is favourable to the implementation of water reuse. The main barriers hampering implementation of water reuse were economic, water management and environmental thematic subjects.
- The distribution costs were not considered for the other options but it can be stated that a judicious combination between the location of the wastewater source and the end-user location is crucial. Ideally, the potential reusers should be situated at a lower elevation than the source and the distance should be minimised. If reclaimed water has to be transported uphill after treatment for a long distance, the costs outreach greatly the treatment costs.

b) Water management strategies in agriculture

The case study of Egypt:

- The introduction of the gated pipe contributes to reduce the quality deterioration of the water available for irrigation practices – by reducing the drained water re-pumped into the system - and to improve the equity of the system.
- Specific incentives should be introduced in order to enhance the adoption of the proposed innovative technology since, notwithstanding the energy cost saving due to the reduce amount of drained water re-pumped into the system, farmers' income decreases due to the investment and O&M costs of the gated pipe technology.
- The joint introduction of the technological innovation and of a new policy of water supply could achieve the objective to reduce the amount of water used by agriculture without affecting the level of satisfaction of farmers.
- Since different and conflicting objectives can be achieved, it is crucial to define the priorities among the different objectives – reduction of water demand, reduction of the reused drainage, economic performance of the farmers and their level of satisfaction – in order to design the most effective policies of water in the area.

The case study of Morocco:

- The use of TWW allows the conservation of relevant amounts of fresh water and helps to save important amounts of fertilizing elements which results in lower production costs for farmers.

- The increase in TWW supply must be associated with a sound water resource design policy that fills the widespread lack of effective price signals (El Yacoubi and Belghiti, 2002) and restructures the reuse funding.

- Subsidies - through the water pricing policy as well as through the innovation policy - are needed to enhance the use of TWW. Although they are not justified from a pure economic point of view, a more holistic evaluation should also take into account the economic value of the environmental benefits that TWW reuse can generate.

- It is important to stress that local conditions could change in the future: while decreases in the treatment cost of wastewater reuse could contribute to its reuse, an increasing water scarcity for the agricultural sector could eliminate the choice between the sources that is still preserved in the Moroccan irrigation sector; in this scenario, the total or partial substitution of fresh water with different sources of non-uniform quality irrigation water will become one of the main future research lines to be explored.

The case study of Tunisia:

- The fieldwork conducted in the area in three different periods has proven to be essential for specifying adequately the DST model in the area of study. This has permitted to analyze more accurately the impact of water technologies and economic instruments at different levels of aggregation, farm and basin scales. Based on this, the study permits to discuss the development of specific policies of water conservation to address water scarcity problem in the area, that may be distinct across different farm types and in the whole basin.
- In relation to the different scenarios simulated, we can conclude that there is a trade-off between the environmental consequences (e.g. use of water) and the socio-economic consequences (e.g farm income) when a given technology or economic instrument is applied. In all scenarios, we can observe that positive environmental consequences, such as less water being used, can be off-set by negative socio-economic effects, such a farm-income loss. Specifically, the environmentally preferred scenario (not subsidized treated wastewater) that results in substantial water savings inflicts a serious income loss to the farmers. In general terms, the most balanced scenario is the technology scenario that can combine effectively positive environmental and socioeconomic effects, by reducing water use and preserving farm income. An increase in irrigation technical efficiency reduces water consumption while maintaining farm income across all farm types and in the whole basin. Combining water sources, fresh and treated wastewater, is also proven to be effective to attain well-balanced environmental and socioeconomic consequences. A policy that will encourage mixing fresh and treated waters can lead to positive outcomes for conserving water resources and maintaining rural livelihoods
- From our analysis, we can also conclude that there is not a unique policy that could lead to positive ecological and social consequences across all farm types and in the basin as a whole. Different types of farms in the area could have different responses to a given technological or socio-economic policy and thus different consequences can be expected. Farms that cultivate annual crops are more flexible to adapt their cropping patterns when a given technology or pricing system is applied. In contrast, farms that grow permanent crops have less capacity to adapt their cropping pattern.

- In relation to the current subsidies applied in Tunisia for wastewater, we can conclude from our study, that it has proven to be a successful instrument to encourage the use of treated wastewater for agricultural production. This opens the way, in the context of the MADFORWATER project, to support the use of this type of water and thus the development of related technologies and pricing schemes.
- Alongside, we can also conclude from our study that the farmers' willingness to pay for an extra unit of water is higher than the actual price currently paid in the region. This holds both at farm level and for the basin as a whole and shows that it will be possible to develop a sound water tariffs and water quotas policy in the area of study.
- In sum, we can conclude that encouraging well-balanced water policies based in an efficient combination of technology and economic instruments will lead to positive effects in the area of study in Tunisia. In addition, engaging stockholders is key for fostering the adoption of new technologies and for analyzing the consequences of the application of these policies. In general, this study contributes to support and enhance the water policies that Tunisia is already applying. It intends to encourage water policy making with the development of new water technologies and socio-economic instruments that will be environmentally proof, economically sound and socially acceptable

5. Symbols and abbreviations

CRDA	Regional Commissariat for Agricultural Development (Commissariat Régional de Développement Agricole)
DCWW	Drainage Canal WasteWater
DST	Decision Support Tool
F_1, F_2 and F_3	Farm types
FAO	Food and Agriculture Organisation
FHNW	FachHochschule NordWestschweiz
FW	Freshwater
FWS	Free Water Surface
GAMS	General Algebraic Modeling System
GDA	Agricultural Development Groups (Groupement Développement Agricole)
IAMB	Centro Internazionale di Alti Studi Agronomici Mediterranei- Istituto Agronomico Mediterraneo di Bari
MAC	Mediterranean African Countries
MAP	MonoAmmonium Phosphate
MCA	Multi-Criteria Analysis
MENA	Middle East and North African
MWW	Municipal WasteWater
NWRC	National Water Research Centre
TWW	Treated Wastewater
UPM	Universidad Politecnica de Madrid
WWTP	WasteWater Treatment Plant

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7. Annexes

Annex 1: Strategies and economic instruments for WW management (Task 5.2 : FHNW)

1. Detailed Material and Methods, and Results for the water reuse implementation potential assessment

Table 55: Detailed description of the thematic subjects, key questions, quantitative and semi-quantitative indicators with possible data sources. N/Av stands for 'not available'

Thematic subject	Key question	Indicator	Description	Unit	References
Economy	-What is the official financial development assistance (gross expenditure) for water supply and sanitation?	Total official financial development (gross disbursement) assistance for water supply and sanitation for water supply and sanitation by recipient per WW production in a country and year	Total official financial development (gross disbursement) for water supply and sanitation by recipient as a degree for amount of water and sanitation related to Official Development Assistance that is part of a national government coordinated spending plan per WW production in a country and year. Note, converted from USD/m3 to EUO/m3 with the conversion factor: 0.89 (CoinMill 2019).	Euro / m^3 produced wastewater	UN – SDG Indicators 6.a.1 Global Database in Esteve et al. (2017)
	-What is the level of economic water security?	Economic water security	Composite indicator based on: · Coefficient variation of rainfall - years · Coefficient variation of rainfall - months · Storage Ratio · Reliability · Water Stress · Storage Drought duration length index · Data availability counting → Broad economy index · Water productivity in Agriculture · Self-sufficiency in Agriculture → Agriculture index · Water productivity in Energy	N/Av (ratio of max. 20)	(Snethlage et al. 2018)

Thematic subject	Key question	Indicator	Description	Unit	References
			· Minimum platform for electricity production → Energy index		
	-What are the financial subsidies for water use in agriculture?	Water pricing for agriculture	Tariffs for water use in agriculture	Euro / m^3	(Esteve et al. 2019; Australian Government 2019)
	-What are the financial subsidies for water use in agriculture?	Financial subsidies	A sum of money granted by the state or a public body to help a water reclamation, irrigation of farms keep the price of a commodity or service low.	% reduction	(Esteve et al. 2019)
Water Management	-What is the transboundary water dependency ratio?	Transboundary Water Bodies Dependency Ratio in the Northern African region	The dependency water volume ratio between countries in the Northern African region.	%	2nds Arab State of Water Report in Esteve et al.(2017)
	-What is the share of produced volume of industrial and municipal wastewater per total population in a country?	Share of annual produced industrial and municipal wastewater volume per total population in a country	Share of produced water volume by means of industrial and municipal wastewater before treatment per total population, which includes all persons physically present within the present geographical boundaries of countries at the mid-point of the reference period.	m^3/(a*inhabitants)	(FAO - UN Food and Agriculture Organisation 2016; University of Tunis El Manar 2018; Direction Générale du Génie Rural et de l'Exploitation des Eaux 2017; Commissariat Regional au Developpement Agricole Nabeul 2016), own developement
	- What is the share of treated to produced volume of industrial and municipal wastewater?	Share of annual treated to produced industrial and municipal wastewater	Share of annual treated to produced industrial and municipal wastewater	%	2nds Arab State of Water Report in (Esteve et al. 2017) (FAO - UN Food and Agriculture Organisation 2016; University of Tunis El Manar 2018; Direction Générale du Génie Rural et de l'Exploitation des Eaux 2017; Commissariat Regional au Developpement Agricole Nabeul 2016), own development
	-What is the share of harvested irrigated crop area per cultivated area?	Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)	Percent of total harvested irrigated crop area. It refers to the crops grown under full control irrigation . Areas under double irrigated cropping (same area cultivated and irrigated twice a year) are counted twice. Therefore the total area may be larger than the full/partial control equipped area under , which gives an indication of the cropping intensity. The total is only given if information on all irrigated crops in the country is available per cultivate area (arable land area + permanent crops area).	%	(FAO - UN Food and Agriculture Organisation 2016), own development

Thematic subject	Key question	Indicator	Description	Unit	References
Policy and institutional	-What is the proportion of monitoring and reporting systems in comparison to other countries?	Proportion of monitoring and reporting system between African countries reported on by country	Proportion of monitoring and reporting system between different African countries reported on by country: [%].	%	(Esteve et al. 2017)
	-What is the degree of implementation of national monitoring and reporting system?	Degree of implementation of national monitoring and reporting system	Degree of implementation of national monitoring and reporting system [%].	%	(FAO - UN Food and Agriculture Organisation 2016)
Legislation	- What is the quality of contract enforcement, property rights, and the courts in each country?	World governance index, rule of law	This composite indicator quantifies the ability of a country to abide the quality of contract enforcement, property rights, and the courts	%	(Kaufmann, Kraay, and Mastruzzi 2010)
	- What is the regulation for food and non-food crop irrigation with reclaimed water?	Compliance for food and non-food crop irrigation with reclaimed water	Legal compliance, weather water reclamation in food and non-food crop irrigation is allowed in a country	ranking: yes, partly, no	Own development, and Mueller (2018), and intended stakeholder survey by Mueller et al. (FHNW)
Society	-What is the degree of implementation of equitable water and wastewater tariffs?	Degree of implementation of equitable and efficient water supply and wastewater tariffs	Degree of implementation of equitable and efficient water supply and wastewater tariffs in a country.	%	2nds Arab State of Water Report in Esteve et al. (2017)
	-What share of population is using improved sanitation services?	Share of using improved sanitation services	Share of using improved sanitation services in a country.	%	UN – SDG Indicator Global Database SDG 6.2.1 in Esteve et al. (2017)
	-What is the social acceptance of a country towards water reuse for agriculture?	Social acceptance in a country towards the water reuse for agriculture	The social acceptance of inhabitants of a country towards water reclamation for irrigation (food and non-food crops, municipal and industrial wastewater).	N/Av	Intended stakeholder survey by Mueller et al. (2019)
Environment	-What is the status of national water reuse regulations for irrigation in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	Compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guideline	Compliance of national water reuse regulations e in comparison with the BS ISO 16072-2:2015 water quality guideline	ranking: higher, moderate, lower	Own development, and Mueller (2018), and intended stakeholder survey by Mueller et al (2019).
	-What is the share of the area equipped for irrigation that has become salinized?	Percent of area equipped for irrigation that has become salinized	Percent of area equipped for irrigation that has become salinized due to mineral build up caused by inadequate drainage.	%	(FAO - UN Food and Agriculture Organisation 2016)

Table 56: Scoring of water reuse level: lover, moderate, and higher for each indicator. N/Av stands for not available

Thematic subject	Key question	Indicator	Unit	Scoring
Economy	-What is the official financial development assistance (gross expenditure) for water supply and sanitation?	Total official financial development (gross disbursement) assistance for water supply and sanitation for water supply and sanitation by recipient per WW production in a country and year	Euro / m3 produced wastewater	- lower: 0 - 0.33 Euro/m3 - moderate: >0.33 - 0.66 Euro/m3 - higher: 0.66 >= - 1 Euro/m3
	-What is the level of economic water security?	Economic water security	N/Av (ratio of max. 20)	- lower: 0 - 6.6 - moderate: <6.6 - 13.2 - higher: <13.2 - 20
	-What is the water pricing for agriculture?	Water pricing for agriculture	Euro / m^3	- lower: 0 - 33.3% - moderate: <33.3 - 66.6% - higher: <66.6 - 100%
	-What are the financial subsidies for water use in agriculture?	Financial subsidies	% reduction	- lower: <66.6 - 100% - moderate: <33.3 - 66.6% - higher: 0 - 33.3%
Water Management	-What is the transboundary water dependency ratio?	Transboundary Water Bodies Dependency Ratio in the Northern African region	%	- lower: <66.6 - 100% - moderate: <33.3 - 66.6% - higher: 0 - 33.3%
	-What is the share of produced volume of industrial and municipal wastewater per total population in a country?	Share of annual produced industrial and municipal wastewater volume per total population in a country	$m^3/(a*inhabitants)$	- lower: <66.6 - 100% - moderate: <33.3 - 66.6% - higher: 0 - 33.3%
	-What is the treated volume of industrial and municipal wastewater?	Share of annual treated to produced industrial and municipal wastewater	%	- lower: 0 - 33.3% - moderate: <33.3 - 66.6% - higher: <66.6 - 100%
	-What is the share of harvested irrigated crop area per cultivated area?	Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)	%	- lower: <66.6 - 100% - moderate: <33.3 - 66.6% - higher: 0 - 33.3%
Policy and institutional	-What is the proportion of monitoring and reporting system in comparison to other countries?	Proportion of monitoring and reporting system between African countries reported on by country	%	- lower: 0 - 33.3% - moderate: <33.3 - 66.6% - higher: <66.6 - 100%
	-What is the degree of implementation of national monitoring and reporting system?	Degree of implementation of national monitoring and reporting system	%	- lower: 0 - 33.3% - moderate: <33.3 - 66.6% - higher: <66.6 - 100%
Legislation	-What is the quality of contract enforcement, property rights, and the courts in each country?	World governance index, rule of law	%	- lower: 0 - 33.3% - moderate: <33.3 - 66.6% - higher: <66.6 - 100%
	-What is the regulation for food and non-food crop irrigation with reclaimed water?	Compliance for water reclamation in food and non-food crop irrigation	ranking: yes, partly, no	- lower: yes, food and non-food crops - moderate: partly, non-food crop - higher: no, not allowed

Social	-What are the conditions to equitable water and wastewater options?	Degree of implementation of equitable and efficient water supply and wastewater tariffs	%	- lower: 0 - 33.3% - moderate: <33.3 - 66.6% - higher: <66.6 - 100%
	-What share of population is using improved sanitation services?	Share of using improved sanitation services	%	- lower: 0 - 33.3% - moderate: <33.3 - 66.6% - higher: <66.6 - 100%
	-What is the social acceptance of a country towards water reclamation for agriculture?	Social acceptance in a country towards the water reclamation for agriculture	N/Av	N/Av
Environment	-What is the status of national water reuse regulations for irrigation in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	Compliance of national water reuse regulations for irrigation in comparison with the BS ISO 16072-2:2015 water quality guideline	ranking: higher, moderate, lower	- lower: Cat. D, irrigation of industrial and seeded crops: TSS: 140, BOD: 100, TC: no values - moderate: Cat. C, irrigation of non-food crops: TSS: 50, BOD: 35, TC: 10,000 - higher: Cat. A and B, B as the threshold value includes: irrigation of processed food crops: TSS: 25, BOD: 20, TC: 1,000
	- What is the share of the area equipped for irrigation that has become salinized?	Percent of area equipped for irrigation that has become salinized	%	- lower: 66.66 – 100% - moderate: < 33.33 – 66.66% - higher: <0 – 33.33%

Table 57: Investigation of the situation in Egypt, Tunisia, Morocco, and Australia related to possible wastewater reclamation. N/Av stands for 'not available'

Thematic subject	Key question	Indicator	Result Morocco	Result Tunisia	Result Egypt	Result Australia	Unit	Reference
Economy	- What is the official financial development assistance (gross expenditure) for water supply and sanitation?	Total official financial development (gross disbursement) assistance for water supply and sanitation for water supply and sanitation by recipient per WW production in a country and year	0.246	0.358	0.017	N/Av	Euro / m^3 produced wastewater	UN – SDG Indicators 6.a.1 Global Database in Esteve et al. (2017)
	- What is the level of economic water security?	Economic water security	13.33	13	15.16	8	N/Av (ratio of max. 20)	(Snethlage et al. 2018)
	- What is the water pricing for agriculture?	Water pricing for agriculture	0.15	0.04	0	1.09	Euro / m^3	(Esteve et al. 2019; Australian Government 2019)
	- What are the financial subsidies for water use in agriculture?	Financial subsidies	N/Av	50	100%	N/Av	% reduction	(Esteve et al. 2019)
Water Management	- What is the transboundary water dependency ratio?	Transboundary Water Bodies Dependency Ratio in the Northern African region	0	8	97	0	%	2nds Arab State of Water Report in Esteve et al. (2017), (FAO - UN Food and Agriculture Organisation 2016)

Thematic subject	Key question	Indicator	Result Morocco	Result Tunisia	Result Egypt	Result Australia	Unit	Reference
	- What is the share of produced volume of industrial and municipal wastewater per total population in a country?	Share of annual produced industrial and municipal wastewater volume per total population in a country	29.5	42.8	119.51	107.5	m3/(a*inhabitants)	(FAO - UN Food and Agriculture Organisation 2016; University of Tunis El Manar 2018; Direction Générale du Génie Rural et de l'Exploitation des Eaux 2017; Commissariat Regional au Developpement Agricole Nabeul 2016)
	- What is the share of harvested irrigated crop area per cultivated area?	Percent of total harvested irrigated crop area (full control irrigation) per cultivated area (arable land + permanent crops)	23.7	59.2	38.8	95.5	%	(FAO - UN Food and Agriculture Organisation 2016)
	- What is the share of harvested irrigated crop area per cultivated area?	Total harvested irrigated crop area (full control irrigation)	18.4	8.6	185.0	3.8	%	(FAO - UN Food and Agriculture Organisation 2016)
Policy and institutional	- What is the proportion of monitoring and reporting system in comparison to other countries?	Proportion of monitoring and reporting system between African countries reported on by country	N/Av	95.2	51.2	N/Av	%	(Esteve et al. 2017)
	- What is the degree of	Degree of implementation of	N/Av	74.5	100	N/Av	%	(FAO - UN Food and Agriculture Organisation 2016)

Thematic subject	Key question	Indicator	Result Morocco	Result Tunisia	Result Egypt	Result Australia	Unit	Reference
	implementation of national monitoring and reporting system?	national monitoring and reporting system						
Legislation	- What is the quality of contract enforcement, property rights, and the courts in each country?	World governance index, rule of law	48.56	56.25	32.69	93.27	%	(Kaufmann, Kraay, and Mastruzzi 2010)
	- What is the regulation for food and non-food crop irrigation with reclaimed water?	Compliance for water reclamation in food and non-food crop irrigation	YES	partly	partly	N/Av	ranking: yes, partly, no	Own development, and (Mueller 2018), and intended stakeholder survey by Mueller et al. (2019)
Social	- What are the conditions to equitable water and wastewater options?	Degree of implementation of equitable and efficient water supply and wastewater tariffs	N/Av	58	100	N/Av	%	2nds Arab State of Water Report in Esteve et al. (2017)
	- What share of population is using improved sanitation services?	Share of using improved sanitation services	76.71	91.59	94.72	100	%	UN – SDG Indicator Global Database SDG 6.2.1 in Esteve et al. (2017)
	- What is the social acceptance of a country towards water reclamation for agriculture?	Social acceptance in a country towards the water reclamation for agriculture	N/Av	N/Av	N/Av	N/Av	N/Av	Intended stakeholder survey by Mueller et al. (2019)
Environment	- What is the status of national water reuse	Compliance of national water reuse regulations for irrigation in comparison with the BS	lower	higher	lower	N/Av	ranking: higher, moderate, lower	Own development, and (Mueller 2018), and intended stakeholder

Thematic subject	Key question	Indicator	Result Morocco	Result Tunisia	Result Egypt	Result Australia	Unit	Reference
	regulations for irrigation in comparison with the international BS ISO 16075-2: 2015 water quality guideline?	ISO 16072-2:2015 water quality guideline						survey by Mueller et al. (2019)
	- What is the share of the area equipped for irrigation that has become salinized?	Percent of area equipped for irrigation that has become salinized	10.4	21.83	N/Av	8.3	%	(FAO - UN Food and Agriculture Organisation 2016)

2. Cost factors and weighting profile

Table 58: Cost factors considered for Egypt, Morocco, and Tunisia. '-'stand for 'no data available' or 'not defined

Country	Parameters	Unit	Default value	Reference	Comment
Egypt	Currency	[EGP]	Egyptian Pound		The reference community is based on USD from 2006.
	Exchange rate to USD 2006	[EGP / USD]	5.772 (Jan 2006) 7.319	(European Commission 2019) (Coinnews Media Group LLC 2018)	To define the exchange rate, it is recommended to use the exchange rate from 2006 and to include inflation rate or other evolution factors since 2006 (European Commission, n.d.).
	Land cost	[USD/ha]	10,000	-	Own estimation was used for the assessment
	Electricity cost 2018	[USD/kWh]	0.02	(GlobalPetrolPrices.com 2018)	Average electricity cost should be used.
	Personal cost	[EGP/per month]	3,121	(Economic Research Institute 2019)	Median Base Salary for Blue Collar Worker
	Discount rate (r) 9.7.2017	[%/a]	19.25	(Central Intelligence Agency 2019)	Real interest rate r = nominal interest rate (i) – actual inflation rate (p)
Morocco	Currency	[MAD]	Moroccan dirham		The reference community is based on USD from 2006.
	Exchange rate to USD 2006	[MAD / USD]	9.246 (Jan 2006) 11.724	(European Commission 2019) (Coinnews Media Group LLC 2018)	To define the exchange rate, it is recommended to use the exchange rate from 2006 and to include inflation rate or other evolution factors since 2006 (European Commission, n.d.).
	Land cost	[USD/ha]	10,000	-	Own estimation was used for the assessment
	Electricity cost 2018	[USD/kWh]	0.11	(GlobalPetrolPrices.com 2018)	Average electricity cost should be used.
	Personal cost	[MAD/per month]	3,957	(Economic Research Institute 2019)	Median Base Salary for Blue Collar Worker
	Discount rate (r) 31.12.2010	[%/a]	6.5	(Central Intelligence Agency 2019)	Real interest rate r = nominal interest rate (i) – actual inflation rate (p)
Tunisia	Currency	[TND]	Tunisian dinar		The reference community is based on USD from 2006.
	Exchange rate to USD 2006	[TND / USD]	1.361 (2006) 1.726	(European Commission 2019) (Coinnews Media Group LLC 2018)	To define the exchange rate, it is recommended to use the exchange rate from 2006 and to include inflation rate or other evolution factors since 2006s (European Commission, n.d.).
	Land cost	[USD/ha]	10,000	-	Own estimation was used for the assessment
	Electricity cost 2018	[USD/kWh]	0.07	(GlobalPetrolPrices.com 2018)	Average electricity cost should be used.
	Personal cost	[TND/per month]	2250-3000	(Global Logistic Cluster 2014)	Manual Skilled Labour
	Discount rate (r) 31.12.2010	[%/a]	5.75	(Central Intelligence Agency 2019)	Real interest rate r = nominal interest rate (i) – actual inflation rate (p)

Table 59: Weighting profile applied with assessment criteria for multi criteria analysis with qualitative or semi-quantitative information. '-'stand for 'no data available' or 'not defined

Technical evaluation	**Weight**	**Requirements and impacts**	**Weight**
Reliability	Important	Power demand	Regular
Ease to upgrade	-	Chemical demand	-
Adaptability to varying flow	-	Odor generation	-
Adaptability to varying quality	Important	Impact on ground water	-
Ease of O & M	Very Important	Land requirement	-
Ease of construction	-	Cost of treatment	Important
Ease of demonstration	-	Quantity of sludge production	-

3. Detailed results for the assessment A

Table 60: Top-ranking options for treating municipal wastewater to comply with ISO guidelines in Egypt, Morocco and Tunisia based on cost (C1-C3) and weights (W1-W3

Typical municipal wastewater quality (MWW)						
Ranking	**Egypt**	**Cost** [USD/m^3]	**Morocco**	**Cost** [USD/m^3]	**Tunisia**	**Cost** [USD/m^3]
Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw						
C1	Title 22: Belgium	0.97	Title 22: Belgium	0.59	Title 22: Belgium	0.52
C2	Soil treatment: Israel	1.15	Title 22: USA I	0.66	Title 22: USA I	0.61
C3	Title 22: USA I	1.19	Only disinfection Benchmark	0.68	Only disinfection Benchmark	0.65
W1	Only disinfection Benchmark	1.19	Only disinfection Benchmark	0.68	Only disinfection Benchmark	0.65
W2	Lagooning: South Africa	1.29	Lagooning: South Africa	0.74	Lagooning: South Africa	0.70
W3	Lagooning: Israel	1.64	Lagooning: Israel	0.93	Lagooning: Israel	0.87
Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops						
C1	Wetlands: USA	0.80	Wetlands: USA	0.44	Wetlands: USA	0.42
C2	Title 22: Belgium	0.97	Title 22: Belgium	0.59	Title 22: Belgium	0.52
C3	Only disinfection: USA	1.03	Only disinfection: USA	0.61	Only disinfection: USA	0.57
W1	Only disinfection Benchmark	1.19	Only disinfection Benchmark	0.68	Only disinfection Benchmark	0.65
W2	Lagooning: South Africa	1.29	Lagooning: South Africa	0.74	Lagooning: South Africa	0.70
W3	Local MBR: Japan	1.27	Local MBR: Japan	0.73	Local MBR: Japan	0.67
Cat. C: Agricultural irrigation of non-food crops						
C1	Wetlands: USA	0.80	Wetlands: USA	0.44	Wetlands: USA	0.42
C2	Title 22: Belgium	0.97	Title 22: Belgium	0.59	Title 22: Belgium	0.52
C3	Wetlands: Spain	1.01	Wetlands: Spain	0.59	Wetlands: Spain	0.56
W1	Wetlands: Spain	1.01	Wetlands: Spain	0.59	Wetlands: Spain	0.56

W2	Only disinfection Benchmark	1.19	Only disinfection Benchmark	0.68	Only disinfection Benchmark	0.65
W3	Lagooning: South Africa	1.29	Lagooning: South Africa	0.74	Lagooning: South Africa	0.70

Table 61: Top-ranking options for treating municipal wastewater secondary effluent to comply with ISO guidelines in Egypt, Morocco and Tunisia based on cost (C1-C3) and weights (W1-W3)

Ranking	Egypt	Cost [USD/m³]	Morocco	Cost [USD/m³]	Tunisia	Cost [USD/m³]
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)						
Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw						
C1	Lagooning: Australia I	0.39	Lagooning: Australia I	0.23	Lagooning: Australia I	0.22
C2	Title 22: Spain	0.45	Lagooning: Australia II	0.28	Lagooning: Australia II	0.26
C3	Lagooning: Australia II	0.47	Title 22: Spain	0.29	Title 22: Spain	0.26
W1	Wetlands: Spain	1.01	Wetlands: Spain	0.59	Wetlands: Spain	0.56
W2	Only disinfection: Chile	0.93	Only disinfection: Chile	0.55	Only disinfection: Chile	0.52
W3	Lagooning: Australia I	0.39	Lagooning: Australia I	0.23	Lagooning: Australia I	0.22
Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops						
C1	Lagooning: Australia I	0.39	Lagooning: Australia I	0.23	Lagooning: Australia I	0.22
C2	Direct membrane filtration Benchmark Technology	0.40	Direct membrane filtration Benchmark Technology	0.28	Lagooning: Australia II	0.26
C3	Title 22: Spain	0.45	Lagooning: Australia II	0.28	Direct membrane filtration Benchmark Technology	0.26
W1	Wetlands: Spain	1.01	Wetlands: Spain	0.59	Wetlands: Spain	0.56
W2	Only disinfection: Chile	0.93	Only disinfection: Chile	0.55	Only disinfection: Chile	0.52
W3	Lagooning Benchmark Technology	0.58	Lagooning Benchmark Technology	0.35	Lagooning Benchmark Technology	0.33
Cat. C: Agricultural irrigation of non-food crops						
C1	No treatment	0.00	No treatment	0.00	No treatment	0.00
W1	No treatment	0.00	No treatment	0.00	No treatment	0.00

Table 62: Top-ranking treatment trains for treating municipal wastewater and secondary effluents to comply with Moroccan regulations based on cost (C1-C3) and weights (W1-W3)

Ranking	**Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw**	**Cost** [USD/m^3]	**Moroccan Irrigation Regulation - Cat B & C: irrigation of other crops**	**Cost** [USD/m^3]
	Typical municipal wastewater quality (MWW)			
C1	Wetlands: Nicaragua	0.16	Wetlands: Nicaragua	0.16
C2	Wetlands: Brazil	0.17	Wetlands: Brazil	0.17
C3	Lagooning: Australia I	0.23	Lagooning: Australia I	0.23
W1	Wetlands: Spain	0.59	Wetlands: Spain	0.59
W2	Only disinfection: Chile	0.55	Only disinfection: Chile	0.55
W3	Lagooning Benchmark Technology	0.35	Lagooning Benchmark Technology	0.35
	Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)			
C1	No treatment	0.00	No treatment	0.00
W1	No treatment	0.00	No treatment	0.00

Table 63: Top-ranking treatment trains for treating municipal wastewater and secondary effluents to comply with Egyptian regulations based on cost (C1-C3) and weights (W1-W3)

Ranking	**Egyptian wastewater reuse regulation - Level A: landscape irrigation in urban areas**	**Cost** [USD/m^3]	**Egyptian wastewater reuse regulation - Level B: agriculture purposes in desert areas**	**Cost** [USD/m^3]
	Typical municipal wastewater quality (MWW)			
C1	Wetlands: USA	0.80	Lagooning: Australia I	0.39
C2	Title 22: Belgium	0.97	Only disinfection: Brazil	0.51
C3	Only disinfection: USA	1.03	Wetlands: USA	0.80
W1	Only disinfection Benchmark Technology	1.19	Wetlands: Spain	1.01

Ranking	Egyptian wastewater reuse regulation - Level A: landscape irrigation in urban areas	Cost [USD/m³]	Egyptian wastewater reuse regulation - Level B: agriculture purposes in desert areas	Cost [USD/m³]
W2	Lagooning: South Africa	1.29	Lagooning: Australia I	0.39
W3	Local MBR: Japan	1.27	Only disinfection: Brazil	0.51
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)				
C1	Direct membrane filtration Benchmark Technology	0.40	Direct membrane filtration Benchmark Technology	0.40
C2	Title 22: Spain	0.45	Title 22: Spain	0.45
C3	Only disinfection: Brazil	0.51	Only disinfection: Brazil	0.51
W1	Wetlands: Spain	1.01	Wetlands: Spain	1.01
W2	Only disinfection: Chile	0.93	Only disinfection: Chile	0.93
W3	Lagooning Benchmark Technology	0.58	Lagooning Benchmark Technology	0.58

Table 64: Top-ranking options for treating municipal wastewater and secondary effluents to comply with Tunisian regulations based on cost (C1-C3) and weights (W1-W3)

Ranking	Tunisian wastewater reuse regulation - NT 106.03 standard: irrigation	Cost [USD/m³]	Tunisian wastewater reuse regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use	Cost [USD/m³]
Typical municipal wastewater quality (MWW)				
C1	Wetlands: Senegal	0.37	Only disinfection: Chile	0.52
C2	Wetlands: USA	0.42	Title 22: Belgium	0.52
C3	Title 22: Belgium	0.52	Wetlands: Spain	0.56
W1	Wetlands: Spain	0.56	Wetlands: Spain	0.56
W2	Only disinfection Benchmark Technology	0.65	Only disinfection: Chile	0.52
W3	Lagooning: South Africa	0.70	Only disinfection Benchmark Technology	0.65
Typical municipal wastewater treatment plant secondary effluent (MWW-Eff)				
C1	Wetlands: Nicaragua	0.15	Wetlands: Nicaragua	0.15
C2	Wetlands: Brazil	0.16	Wetlands: Brazil	0.16
C3	Lagooning: Australia I	0.22	Wetlands: Peru	0.22

W1	Wetlands: Spain	0.56	Wetlands: Spain	0.56
W2	Only disinfection: Chile	0.52	Only disinfection: Chile	0.52
W3	Lagooning Benchmark Technology	0.33	Lagooning Benchmark Technology	0.33

Table 65: List of all strategies developed from section 3

N°	Wastewater	End-use – water quality regulation	Technology	Country	Quantity [m3/d]	Cost of treatment [USD/m3]
1	MAC - MWW - Typical Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Title 22: Belgium	Egypt	10,000	0.97
2	MAC - MWW - Typical Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Title 22: Belgium	Morocco	10,000	0.59
3	MAC - MWW - Typical Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Title 22: Belgium	Tunisia	10,000	0.52
4	MAC - MWW - Typical Municipal Wastewater quality	Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	Wetlands: USA	Egypt	10,000	0.80
5	MAC - MWW - Typical Municipal Wastewater quality	Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	Wetlands: USA	Morocco	10,000	0.44

N°	Wastewater	End-use – water quality regulation	Technology	Country	Quantity [m3/d]	Cost of treatment [USD/m3]
6	MAC - MWW - Typical Municipal Wastewater quality	Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	Wetlands: USA	Tunisia	10,000	0.42
7	MAC - MWW - Typical Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	Wetlands: USA	Egypt	10,000	0.80
8	MAC - MWW - Typical Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	Wetlands: USA	Morocco	10,000	0.44
9	MAC - MWW - Typical Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	Wetlands: USA	Tunisia	10,000	0.42
10	MAC - MWW - Typical Municipal Wastewater quality	Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw	Wetlands: Nicaragua	Morocco	10,000	0.16
11	MAC - MWW - Typical Municipal Wastewater quality	Moroccan Irrigation Regulation - Cat B & C: irrigation of other crops	Wetlands: Nicaragua	Morocco	10,000	0.16
12	MAC - MWW - Typical Municipal Wastewater quality	Egyptian wastewater reuse regulation - Level A: landscape irrigation in urban areas	Wetlands: USA	Egypt	10,000	0.80
13	MAC - MWW - Typical Municipal Wastewater quality	Egyptian wastewater reuse regulation - Level B: agriculture purposes in desert areas	Lagooning: Australia I	Egypt	10,000	0.39

N°	Wastewater	End-use – water quality regulation	Technology	Country	Quantity [m3/d]	Cost of treatment [USD/m3]
14	MAC - MWW - Typical Municipal Wastewater quality	Tunisian wastewater reuse regulation - NT 106.03 standard: irrigation	Wetlands: Senegal	Tunisia	10,000	0.37
15	MAC - MWW - Typical Municipal Wastewater quality	Tunisian wastewater reuse regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use	Only disinfection: Chile	Tunisia	10,000	0.52
16	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Lagooning: Australia I	Egypt	10,000	0.39
17	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Lagooning: Australia I	Morocco	10,000	0.23
18	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. A: Unrestricted urban irrigation and agricultural irrigation of food crops consumed raw	Lagooning: Australia I	Tunisia	10,000	0.22
19	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	Lagooning: Australia I	Egypt	10,000	0.39
20	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	Lagooning: Australia I	Morocco	10,000	0.23

N°	Wastewater	End-use – water quality regulation	Technology	Country	Quantity [m3/d]	Cost of treatment [USD/m3]
21	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. B: Restricted urban irrigation and agricultural irrigation of processed food crops	Lagooning: Australia I	Tunisia	10,000	0.22
22	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	No treatment	Egypt	10,000	0
23	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	No treatment	Morocco	10,000	0
24	MAC - MWW - Typical Effluent Municipal Wastewater quality	Cat. C: Agricultural irrigation of non-food crops	No treatment	Tunisia	10,000	0
25	MAC - MWW - Typical Effluent Municipal Wastewater quality	Moroccan Irrigation Regulation - Cat A: irrigation of crops to be eaten raw	No treatment	Morocco	10,000	0
26	MAC - MWW - Typical Effluent Municipal Wastewater quality	Moroccan Irrigation Regulation - Cat B & C: irrigation of other crops	No treatment	Morocco	10,000	0
27	MAC - MWW - Typical Effluent Municipal Wastewater quality	Egyptian wastewater reuse regulation - Level A: landscape irrigation in urban areas	Direct membrane filtration Benchmark Technology	Egypt	10,000	0.40
28	MAC - MWW - Typical Effluent Municipal Wastewater quality	Egyptian wastewater reuse regulation - Level B: agriculture purposes in desert areas	Direct membrane filtration Benchmark Technology	Egypt	10,000	0.40

N°	Wastewater	End-use – water quality regulation	Technology	Country	Quantity [m3/d]	Cost of treatment [USD/m3]
29	MAC - MWW - Typical Effluent Municipal Wastewater quality	Tunisian wastewater reuse regulation - NT 106.03 standard: irrigation	Wetlands: Nicaragua	Tunisia	10,000	0.15
30	MAC - MWW - Typical Effluent Municipal Wastewater quality	Tunisian wastewater reuse regulation - Norm 106.03 revised, Cat III: infiltration of groundwater for agricultural use	Wetlands: Nicaragua	Tunisia	10,000	0.15
31	MADFORWATER-DCW	Not defined	MADFORWATER Pilot	Egypt	10,000	0.31
32	MADFORWATER-DCW	Not defined	MADFORWATER Pilot	Egypt	1,000	0.51
33	MADFORWATER-DCW	Not defined	MADFORWATER Pilot	Morocco	10,000	0.18
34	MADFORWATER-DCW	Not defined	MADFORWATER Pilot	Morocco	1,000	0.30
35	MADFORWATER-DCW	Not defined	MADFORWATER Pilot	Tunisia	10,000	0.17
36	MADFORWATER-DCW	Not defined	MADFORWATER Pilot	Tunisia	1,000	0.28
37	MADFORWATER-FVPWW	Not defined	MADFORWATER Pilot	Egypt	10,000	1.44
38	MADFORWATER-FVPWW	Not defined	MADFORWATER Pilot	Egypt	1,000	2.20
39	MADFORWATER-FVPWW	Not defined	MADFORWATER Pilot	Morocco	10,000	0.88
40	MADFORWATER-FVPWW	Not defined	MADFORWATER Pilot	Morocco	1,000	1.22
41	MADFORWATER-FVPWW	Not defined	MADFORWATER Pilot	Tunisia	10,000	0.81
42	MADFORWATER-FVPWW	Not defined	MADFORWATER Pilot	Tunisia	1,000	1.14
43	MADFORWATER-MWW	Not defined	MADFORWATER Pilot	Egypt	10,000	1.10

N°	Wastewater	End-use – water quality regulation	Technology	Country	Quantity [m3/d]	Cost of treatment [USD/m3]
44	MADFORWATER-MWW	Not defined	MADFORWATER Pilot	Morocco	10,000	0.62
45	MADFORWATER-MWW	Not defined	MADFORWATER Pilot	Tunisia	10,000	0.59
46	MADFORWATER-OMWW	Not defined	MADFORWATER Pilot	Egypt	10,000	0.51
47	MADFORWATER-OMWW	Not defined	MADFORWATER Pilot	Egypt	1,000	0.75
48	MADFORWATER-OMWW	Not defined	MADFORWATER Pilot	Morocco	10,000	0.36
49	MADFORWATER-OMWW	Not defined	MADFORWATER Pilot	Morocco	1,000	0.46
50	MADFORWATER-OMWW	Not defined	MADFORWATER Pilot	Tunisia	10,000	0.32
51	MADFORWATER-OMWW	Not defined	MADFORWATER Pilot	Tunisia	1,000	0.42
52	MADFORWATER-TWW	Not defined	MADFORWATER Pilot	Egypt	10,000	0.92
53	MADFORWATER-TWW	Not defined	MADFORWATER Pilot	Egypt	1,000	1.99
54	MADFORWATER-TWW	Not defined	MADFORWATER Pilot	Morocco	10,000	0.49
55	MADFORWATER-TWW	Not defined	MADFORWATER Pilot	Morocco	1,000	0.96
56	MADFORWATER-TWW	Not defined	MADFORWATER Pilot	Tunisia	10,000	0.45
57	MADFORWATER-TWW	Not defined	MADFORWATER Pilot	Tunisia	1,000	0.89

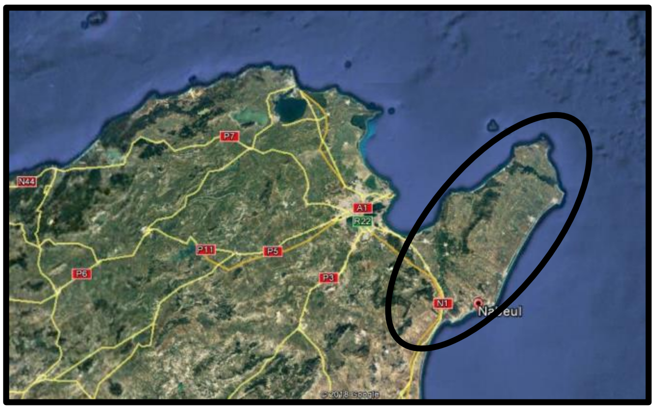
Annex 2: Fieldworks carried out in the Tunisia case study

1. **Fieldwork questionnaire**

MADFORWATER

Etude de cas : La Tunisie

<u>Enquête auprès des agriculteurs</u>



Situation géographique de la zone du projet (Cas de la Tunisie)

Données générales

1. Date de l'enquête :…………………………………………………………………………………………………….
2. Code de l'enquête :…………………………………………………………………………………………………….
3. Nom et prénom de l'enquêteur :……………………………………………………………………………..
4. Délégation :……..
5. Région (Douar) :……..
6. Coordonnées du parcelle (s) :…………………………………………………………………………………..

Données agriculteur

1. Age :…………………………………….   Sexe : …………………..H/F…………………….
2. Niveau de scolarité :
   - Etude primaire
   - Etude secondaire
   - Etude universitaire

- Autres :……………………………………………………………………………………………………

3. Combien de personnes dans votre famille ? :…………………………..……………………….
4. L'agriculture est votre activité principale ?
    - Oui
    - Non

Si non, quel genre de travail exercez-vous ?..

5. Quelle est la marge annuelle que vous recevez anuellement pour chaque hectare ?:………………………………………………………………………………………………….
6. Est-ce qu'il y a plus d'un revenu dans votre famille ?
    - Oui
    - Non

Si oui, quel est le pourcentage de ce revenu dans le revenu familial ? ....

7. Dans quel milieu habitez-vous actuellement ?
    - Urbain
    - Rural
8. Quelle est la distance de votre parcelle par rapport à la route la plus proche?
   ....

Parcelle (s) et culture (s)

1. Quelle est la superficie total de votre exploitation (ha) ?.......................................
2. Etes-vous propriétaire du champ ou locataire ?
   - ❖ Si propriétaire,
     - Quelle la superficie totale exploitée (ha) ? :……………………………………
     - Quel est le prix de vente (dt/ha) ?
       - Pluvial :……………………………………………………………………………
       - Irrigué :…………………………………………………………………………..
   - ❖ Si locataire,

- Quelle est la superficie totale exploitée (ha) ? :……………………………..
- Quel est le prix de location (dt/ha) ?
  - Pluvial :……………………………………………………………………………..
  - Irrigué :……………………………………………………………………………

3. Le prix de vente ou de location de terrain est conditionné par les caractéristiques de la parcelle? ……………………………………………………………………………………………
4. Remplir le tableau suivant pour la caractérisation de chaque culture, superficie, méthode d'irrigation…

Culture	**Superficie (ha)**	**Date de semis et de récolte (mois)**	**Irrigué ? (si, méthode d'irrigation)**

5. Pourquoi cultivez-vous ces cultures et non pas d'autres ?

   ………
6. Avez-vous des terres agricoles non utilisées (ha) ?
   - Oui,……………………………………………………………………………………………………
   - Non
7. Avez-vous des cultures sous serres ?
   - Oui, superficie (ha) ?…………………………………………………………………………
   - Non
8. Quelles rotations faites-vous entre les cultures ? Spécifier cultures, dates et superficie ? Avez-vous des récoltes secondaires ? Cultures associées ?

   ………

9. Pour les cultures permanentes, quel est le coût de production ? Combien d'années prennent pour la production ? Durée de vie des cultures ?

   ……

10. Quelles cultures sont plus risquées ? et quels sont les risques ?

   ……

11. Où vendez-vous vos produits ? Quand ? Quel est le pourcentage de la consommation familial par rapport à la récolte totale ?

   ……

Culture	Rendement (kg/ha)	Prix(dt/kg)	Subvention (dt/ha)	Eau (m^3/ha)	Semences (dt/ha)	Engrais (dt/ha)	Produits phytosanitaires (dt/ha)	Engins agricole (dt/ha)	Main d'œuvre (dt/jour)	Nécessité de la main d'œuvre (heure/ha)

Utilisation de l'eau

1. Quelle est la quantité d'eau que vous avez en total (m^3) ? Comment la quantité d'eau que vous utilisez est-elle limitée? Comment se fait le control et la gestion de l'eau ?

   ……

2. Quelles sources d'eau utilisez-vous ? Quelles cultures irriguez-vous de chaque source ? le prix selon la source ?

Source	**Prix (dt/m^3)**		**Quantité (m^3)**		**Cultures**	**Explication (Puits,barrage…)**
	fixe	**variable**	**Appliquée**	**Max**		
Superficielle						
Souterraine						
Eau traitée						

3. Avec ces quantités, avez-vous suffisamment d'eau pour l'irrigation ? Si no, que faites-vous pour apporter la quantité d'eau necessaire ? (puits illégaux)

……

4. Quel est le mode de distribution d'eau ?
   - Gravitaire
   - En charge
   - Autre………………………………………………………………………………………………………

5. Combien coute l'installation d'un système d'irrigation ? goutte à goutte ? aspersion ? pivot ? quelle durée de vie ont ces systèmes ?

……

6. Combien de puits avez-vous ? et quelles sont ses caractéristiques ? débit de pompage (m^3 /h) ? durée de pompages (h/jour) ? comment se fait la gestion des puits collectifs (maintenance…) ? Combien d'hectares irriguez-vous avec chaque puits ?

……

7. Combien coute l’extraction de l’eau (dt/m^3) ?

……

8. Avez-vous des cultures irriguées avec des eaux traitées ? quelles sont ces cultures ? superficies irriguées aves eaux traitées ? quantité d’eau traitée ?

……

9. Si vous avez la possibilité d'irriguer avec de l'eau traitée, vous préférez utiliser de l'eau fraîche que de l’eau traitée ?
   - Oui
   - Non
10. Si oui, seriez-vous prêt à payer un plus pour utiliser l'eau douce ? Combien (%) ? ……
11. Pour lesquelles des raisons suivantes vous ne préférez pas l'eau traitée ?
    - Vous avez la quantité necessaire pour votre culture
    - Ne faites pas confiance à la qualité de cette eau
    - Vous pensez que ce type d’eau ne sera pas acceptable par l’entourage (Lider, agriculteurs…)
    - Vous pensez qu’avec ce type d’eau, le produit peut avoir plus de difficultés à être vendu ou bien vendu à un prix inférieur.
12. Quels types de restrictions ou des obstacles rencontrés pour l’eau traitée ?

……

13. Pour vous, il est important d'économiser de l'eau ?
    - Reduction des coûts
    - Approvisionnement insuffisant en eau douce ou en eau de surface
    - Manque d’eau dans le futur
    - Raisons environnementales

Main d'œuvre

1. Combien de main d'œuvre avez-vous besoin ? familiale ? contractée fixe ? par saison ?

   ………

2. Quelles sont les taches de la main d'œuvre (gestion, irrigation, collecte…) ?

   ………

3. Combien coûte la main-d'œuvre (dt/jour) ?..

Financement et subvention

1. Vous recevez du financement ou des subventions ? vous demandez un crédit bancaire ? Qui finance votre activité agricole ?

   ………

2. Vous recevez financement o subvention à court terme (financement de semences, fumier, engrais…) ?

   ………

3. Vous recevez financement o subvention à long terme (engins agricole, équipements d'irrigation, puits…) ?

   ………

4. Les subventions sont faites par hectare ou bien par rendement des cultures ?

   ………

Politique agricole

1. Y a-t-il des politiques qui affectent votre activité ? Quelles sont ?

……

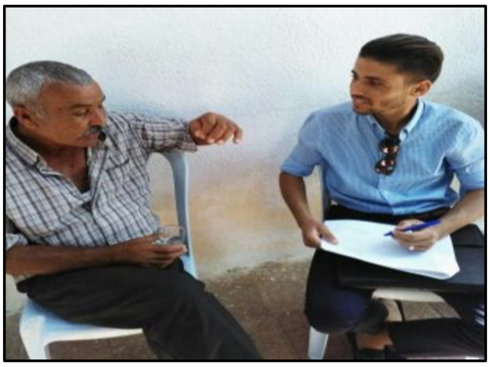
2. Y a-t-il une politique qui vous oblige à cultiver des cultures stratégiques ? quelles sont ces cultures stratégiques ?

……

Commentaires

……
……
……
………..

Annex 3: Fieldworks photos



 MADFORWATER

Annex 4: assumptions

Scenarios	Model parameters		
	Baseline	**Simulated**	**Source**
1- The water availability scenario (TWW use)			
1.1- **Increase in water availability considering water supply from WW reuse**	**F1 – Vegetables (3 ha; irrigated with groundwater** - FW availability in winter = 3700 m³/ha - FW availability in summer = 479 m³/ha - TWW availability = 0 m³/ha - FW price = 0.04 €/m³ - TWW price = 0.02 €/m³	**F1 – Vegetables (3 ha)** - TWW availability in winter = 3700 m³/ha - TWW availability in summer = 3700 m³/ha - TWW price= 0.02 €/m³	* From the three fieldworks carried out in the region * Institutions : CRDA Nabeul, GDA (Souhil, Messadi, Korba, Somaa, Grombalia...) * Water prices: data from official price invoices obtained from the farmers and institutions (GDA)
	F2– Citrus (2 ha; irrigated with surface water) - FW availability in winter = 2500 m³/ha - FW availability in summer = 2000 m³/ha - TWW availability = 0 m³/ha - FW price = 0.04 €/m³	**F2 – Citrus (2 ha)** - TWW availability in winter = 2500 m³/ha - TWW availability in summer = 3500 m³/ha - TWW price = 0.02 €/m³	
	F3 – Citrus + Olive (1.5 ha; irrigated with TWW) - TWW availability in winter = 1000 m³/ha - TWW availability in summer = 500 m³/ha TWW price= 0.02 €/m³	**F3 – Citrus + Olive (1.5 ha)** - TWW availability in winter = 1000 m³/ha - TWW availability in summer = 2000 m³/ha TWW price = 0.02 €/m³	
1.2 – Mix the two types of water TWW + FW (only for F1 and F2, because F3 already use treated waste water)	**F1 – Vegetables (3 ha)** - FW availability in winter = 3700 m³/ha - FW availability in summer = 479 m³/ha - TWW availability in winter = 0 m³/ha - TWW availability in summer = 0 m³/ha - FW price = 0.04 €/m³ - TWW price = 0.02 €/m³	**F1 – Vegetables (3 ha)** - FW availability in winter = 3700 m³/ha - FW availability in summer = 479 m³/ha - TWW availability in winter = 0 m³/ha - TWW availability in summer = 800 m³/ha - FW price = 0.04 €/m³ - TWW price = 0.02 €/m³	
	F2 – Citrus (2 ha) - FW availability in winter = 2500 m³/ha - FW availability in summer = 2000 m³/ha	**F2 – Citrus (2 ha)** - FW availability in winter = 2500 m³/ha - FW availability in summer = 2000 m³/ha	

	- TWW availability = 0 m^3/ha - FW price = 0.04 €/m^3	- TWW availability = 1500 m^3/ha - FW price = 0.04 €/m^3 - TWW price = 0.02 €/m^3	
1.3 – Fertilizer saving coefficient for using TWW	**NOT APPLICABLE** SIM is not available for Tunisia at present. Therefore, based on literature and experts' discussions a third treatment of WW results in low mineral content and thus it does not provide important savings of fertilizers		
2- The technology scenario (Irrigation management)			
2.1- **irrigation efficiency considering innovative technologies : Calibrated nozzles**	- Irrigation efficiency (H) = 0.85 Traditional nozzles = 200 €/ha	- Irrigation efficiency (H) = 0.95 Current: cost of calibrated nozzels is the same as the cost of traditional nozzels	For traditional nozzels: * Literature * Fieldworks * during the fieldworks we have consulted three manufacture firms of irrigation equipment (SOCOOPAC, Espace agricole Chaabani, Societe equipement agricole Nabeul)
3- The policy scenario (Economic instruments for water management)			
3.1- Subsidizing FW (not applicable for F3)	FW price = 0.04 €/m^3	TWW price = 0.02 €/m^3 FW price = 0.02 €/m^3	*Fieldworks *Institutions: CRDA, GDA * Water prices: data from official price invoices obtained from the farmers and institutions (GDA)
3.2- TWW is not subsidized (same price as FW)	TWW price = 0.02 €/m^3	TWW price = 0.04 €/m^3 FW price = 0.04 €/m^3	
3.3- Water pricing	**F1 – Vegetables (3 ha)** FW price (P) = 0.04 €/m^3	**F1 – Vegetables (3 ha)** Gradual increase of 0.02 €/m3 in FW water price for twenty price levels (P1=0.00, . . ., P20=1.00)	
	F2 – Citrus (2 ha) FW price (P) = 0.04 €/m^3	**F2 – Citrus (2 ha)** Gradual increase of 0.02 €/m3 in FW water price for twenty price levels (P1=0.00, . . ., P20=1.00)	

	F3 – Citrus + Olive (1.5 ha) TWW price = 0.02 €/m^3	**F3 – Citrus + Olive (1.5 ha)** Gradual increase of 0.02 €/m3 in TWW water price for twenty price levels (P1=0.00, . . ., P20=1.00)
3.4- Water quotas	**F1 – Vegetables (3 ha)** - FW availability (Wa) = 4179 m^3/ha	**F1 – Vegetables (3 ha)** Gradual decrease of 600 m^3/ha in FW availability (Wa1=6000,… ,Wa10=0)
	F2 – Citrus (2 ha) - FW availability (Wa) = 4500 m^3/ha	**F2 – Citrus (2 ha)** Gradual decrease of 700 m^3/ha in FW availability (Wa1=7000…, Wa10=0)
	F3 – Citrus + Olive (1.5 ha) - TWW availability (Wa) = 1500 m^3/ha	**F3 – Citrus + Olive (1.5 ha)** Gradual decrease of 500 m^3/ha in TWW availability (Wa1= 5000, …, Wa10= 0)